National Aeronautics and Space Administration

OPERA

Observational Products for End-Users from Remote Sensing Analysis

Product Description Document

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

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** Include the JPL Limited Release System (LRS) clearance number for each revision to be shared with foreign partners.*

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1.

2. 1 INTRODUCTION

a. 1.1 Purpose of Description

This document provides an overview of the OPERA (Observational Products for End-Users from Remote Sensing Analysis) data products to be generated by the OPERA Science Data System and provided to the NASA Distributed Active Archive Center(s) (DAAC(s)).

b. 1.2 Scope of Description

This product description document describes the OPERA Level 2 (L2) to Level 3 (L3) products with their notional data layers and posting. This document is not a product specification document. This description document, together with Algorithm Development Team (ADT) L3 requirements, will be used by the OPERA ADT to flow down to a product specification document.

c. 1.3 Applicable and Reference Documents

The applicable documents listed below levy requirements on areas addressed in this document. Reference documents are also cited to provide additional information to readers. In cases of conflict between the applicable documents and this document, the OPERA Project shall review the conflict to find the most effective resolution.

Applicable Documents (ADs):

AD1: SNWG Program-Level Requirements document (Version August 2, 2020)

AD2: OPERA Project requirements document (JPL D-107391)

Reference Documents (RDs):

RD1: NASA EOSDIS Terminology Specification, 423-SPEC-002, Revision A. [link]

RD2: OPERA DIST Product Algorithm Theoretical Basis Document (JPL D-108273)

Bekaert, David, et al. “RAiDER Tropospheric Correction.” Github. [link]

Carroll, Mark, John Townshend, Matthew Hansen, et al. “MODIS Vegetative Cover Conversion and Vegetation Continuous Fields” in *Land Remote Sensing and Global Environmental Change. Remote Sensing and Digital Image Processing* 11 (2010): 725-745. [link]

Claverie, Martin, Junchang Ju, Jeffrey G. Masek, et al. “The Harmonized Landsat and Sentinel-2 surface reflectance data set.” *Remote Sensing of Environment* 219 (2018): 145-161. [link]

Chen, Curtis W., and Howard A. Zebker. “Phase unwrapping for large SAR interferograms: Statistical segmentation and generalized network models.” *IEEE Transactions on Geoscience and Remote Sensing* 40.8 (2002): 1709–1719. [link]

Fattahi, Heresh, Mark Simons, and Piyush Agram. “InSAR time-series estimation of the ionospheric phase delay: An extension of the split range-spectrum technique.” *IEEE Transactions on Geoscience and Remote Sensing* 55.10 (2017): 5984–5996. [link]

Eriksen, Christine. “Why do they burn the ‘bush’? Fire, rural livelihoods, and conservation in Zambia.” *Geographical Journal*, 173.3 (2007): 242-256. [link]

Hansen, Matthew C., et al. “Global percent tree cover at a spatial resolution of 500 meters: First results of the MODIS vegetation continuous fields algorithm.” *Earth Interactions*, 7. 10 (2003):1-15. [link]

Hansen, Matthew C., Peter V. Potapov, Rebecca Moore, Matt Hancher, Svetlana A. Turubanova, Alexandra Tyukavina, David Thau, et al. "High-resolution global maps of 21st-century forest cover change." *Science* 342. 6160 (2013): 850–853. [link]

Jones, John W. "Improved automated detection of subpixel-scale inundation—Revised dynamic surface water extent (DSWE) partial surface water tests." *Remote Sensing* 11.4 (2019): 374. [link]

Li, Jian, and David P. Roy . "A Global Analysis of Sentinel-2A, Sentinel-2B and Landsat-8 Data Revisit Intervals and Implications for Terrestrial Monitoring." *Remote Sensing* 9 (2017) 902. [link]

Liang, Cunren, Piyush Agram, Mark Simons, and Eric J. Fielding, "Ionospheric Correction of InSAR Time Series Analysis of C-band Sentinel-1 TOPS Data," *IEEE Transactions on Geoscience and Remote Sensing* 57.9 (2019): 6755-6773. [link]

NISAR "NASA-ISRO SAR (NISAR) Mission Science Users' Handbook." NASA Jet Propulsion Laboratory (2018): 261. [link]

Nobre, Antonio Donato, et al. "Height Above the Nearest Drainage–a hydrologically relevant new terrain model." *Journal of Hydrology* 404.1–2 (2011): 13–29. [link]

Pekel, Jean-François, Andrew Cottam, Noel Gorelick, and Alan S. Belward. "High-resolution mapping of global surface water and its long-term changes". *Nature* 540 (2016): 418–422. [link]

Potapov, Peter, Matthew C. Hansen, et al. "Landsat Analysis Ready Data for Global Land Cover and Land Cover Change Mapping." *Remote Sensing* 12.3 (2020). [link]

Rosen, Paul A., Scott Hensley, and Curtis Chen. "Measurement and mitigation of the ionosphere in L-band interferometric SAR data." 2010 IEEE Radar Conference. IEEE, (2010): 1459–1463. [link]

Shiroma, Gustavo HX, Marco Lavalle, and Sean M. Buckley. "An Area-Based Projection Algorithm for SAR Radiometric Terrain Correction and Geocoding." *IEEE Transactions on Geoscience and Remote Sensing* 60 (2022): 1–23. [link]

Small, David. "Flattening gamma: Radiometric terrain correction for SAR imagery." *IEEE Transactions on Geoscience and Remote Sensing* 49.8 (2011): 3081–3093. [link]

Ying, Qing, Matthew C. Hansen, Peter V. Potapov, et al. "Global bare ground gain from 2000 to 2012 using Landsat imagery." *Remote Sensing of Environment* 194 (2017): 161-176. [link]

Zhan, Xiwu, Ruth DeFries, Matthew Hansen, John Townshend,Charlene DiMiceli, Robert Sohlberg, Chengqian Huang, MODIS Enhanced Land Cover and Land Cover Change Product Algorithm Theoretical Basis Documents (ATBD), Version 2.0, (1999). [link]

The OPERA Level 1 (L1) requirements are translated into L2 requirements on the various subsystems, including those specifically related to the processing system producing the L2–L3 products. These L2 requirements fall into four general categories: (a) resolution requirements, (b) radiometric and spatial location accuracy requirements, (c) product accuracy requirements, and (d) latency and throughput requirements.

The Committee on Earth Observation Satellites (CEOS) Analysis Ready Data for Land (CARD4L) framework aims to define a community-agreed minimum set of requirements, organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets. CARD4L is the first group to publish formal product specifications for ARD data from synthetic aperture radar (SAR), and the OPERA team has representation on multiple CARD4L advisory groups. While the product specifications by CARD4L are not meant to be exclusive or prescriptive, the OPERA team aims to align with CARD4L guidance where possible.

The NASA Earth Observing System Data and Information System (EOSDIS) nomenclature for classifying mission science products into various processing levels is provided for reference in Table 1.1 [RD1].

Table 1.1: NASA EOSDIS Scientific Data Processing Level Definitions.

Data Level	***Processing Level***
Level 0 (L0)	*Level 0 data products are reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artifacts, e.g., synchronization frames, communications headers, duplicate data removed.*
Level 1A (L1A)	*Level 1A data products are reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters, e.g., platform ephemeris, computed and appended but not applied to the Level 0 data.*
Level 1B (L1B)	*Level 1A data that have been processed to sensor units (not all instruments will have a Level 1B equivalent).*
Level 2 (L2)	*Level 2 data products are derived geophysical variables at the same resolution and location as the Level 1 source data.*
Level 3 (L3)	*Level 3 data products are variables mapped on uniform space-time grid scales, usually with some completeness and consistency.*
Level 4 (L4)	*Level 4 data products are model outputor results from analyses of lower level data, e.g., variables derived from multiple measurements.*

d. 1.4 Products Overview

The Jet Propulsion Laboratory (JPL) OPERA Project is developing three L3 products that respond to the needs identified by various federal agencies during the 2018 cycle (aka cycle-2) of the Satellite Needs Working Group (SNWG) development activities:

1. A near-global Dynamic Surface Water Extent (DSWx) product
2. A near-global land-surface change (DIST) product
3. A North America land-surface displacement (DISP) product

In addition, OPERA will produce two intermediate L2 data products:

4. A North-America land co-registered single look complex (CSLC) product
5. A near-global land-surface radiometric terrain-corrected (RTC) product

An overview of the OPERA products and their input datasets are provided in Figure 1.1. The OPERA Project is following a staggered release schedule as shown in Table 1.2. Table 1.3 provides a summary of key product characteristics, including the spatial coverage and resolution of the products, the start of the product record, and the temporal sampling of the sensors used as input for the products.

This document describes the primary data and metadata layers in each L2–L3 product generated by the OPERA Science Data System (SDS). This includes a description of a) the raster layers with resolutions and geographic information; b) metadata layers, including input data information and auxiliary data for further processing; and c) secondary rasters (when applicable) that are shared across imagery in an image stack. Furthermore, each product is labeled using the convention <name>-<sensor>, where <name> and <sensor> are acronyms for the product and the sensor, respectively. For example, the NISAR displacement product is labeled “DISP-NI.” The sensors and input datasets are abbreviated to S1 (Sentinel-1A/B), HLS (Harmonized Landsat 8 and Sentinel-2A/B), SW (SWOT), and NI (NISAR). See the Acronyms section for definitions. Figure 1.1 shows the breakout of the different products in level and sensor.

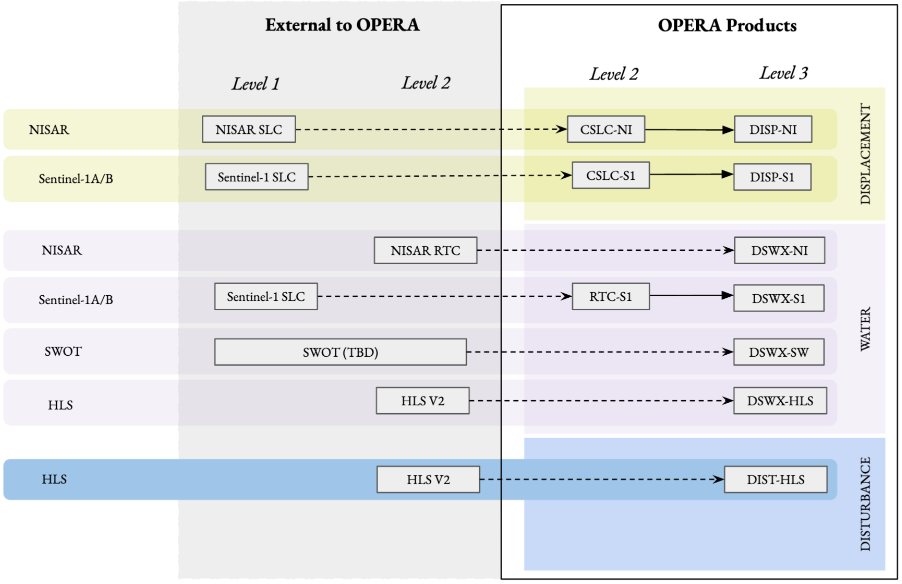

Figure 1.1: OPERA products’ dependency and external input datasets to OPERA products that are accessed through the NASA DAACs.

Table 1.2: Overview of the OPERA product release schedule to the public.

Release	Products	Product Release
1	*Optical* DSWx* *Optical* DIST*	*End of February 2023* *Mid of February 2023 (provisional)* *End of September 2023*
2	*S1A/B RTC* *S1A/B CSLC*	*End of September 2023* *End of September 2023*
3	*NISAR Coreg SLC* *S1A/B DSWx* *NISAR DSWx*	*Beginning of May 2024* *End of July 2024* *End of July 2024*
4	*S1A/B DISP*	*End of November 2024*
5	*NISAR DISP* *SWOT DSWx*	*Beginning of July 2025* *Beginning of July 2025*

*Optical includes both Landsat-8 and Sentinel-2A/B sensors. The optical sensors deliver one product because they use HLS as inputs. *All releases are validated products unless otherwise specified.*

e. 1.5 Organization of this Document

This document is organized according to NASA Earth Data product levels (Level 0, 1, 2, 3). The OPERA Project uses validated L1 data products from existing missions (NISAR, SWOT, Sentinel-1) and projects (HLS) for generation of higher-level products (see Figure 1.1); hence, it does not generate any L0 or L1 products. At higher levels, L2 products are geocoded products measuring a specific geophysical sensor variable, and L3 products are geocoded and uniformly gridded.

Table 1.3: Summary of OPERA product characteristics.

Product Name	**Coverage**	**Sensor**	**Acronym**	**Spatial Resolution**	**Sensor[1] Temporal Sampling*** **	**Beginning of Product Record********
Coregistered Single Look Complex (CLSC)	_North America*_	_Sentinel-1A/B_	_CSLC-S1_	~15 m × 5 m (azimuth x range)	12 days (single sensor + same geometry) † 6 days (constellation + same geometry) †	Based on Sentinel-1 A/B Availability (April 3, 2014 – Sentinel-1A launch) (April 25, 2015 – Sentinel-1B launch)
		NISAR	_CLSC-NI_	~5 m × 3.1/6.25 m (azimuth x range)	12 days (same geometry) †	Based on NISAR Availability
Radiometric Terrain-Corrected (RTC)	_Near-Global**_	_Sentinel-1A/B_	_RTC-S1_	30 m	12 days (single sensor + same geometry) † 6 days (constellation + same geometry) †	From the end of product validation: December 15, 2022
Displacement Product (DISP)	_North America*_	_Sentinel-1A/B_	_DISP-S1_	30 m or ~15 m × 5 m (azimuth x range)	12 days (single sensor + same geometry) † 6 days (constellation + same geometry) †	Based on Sentinel-1 A/B Availability (April 3, 2014 – Sentinel-1A launch) (April 25, 2015 – Sentinel-1B launch)
		NISAR	_DISP-NI_	30 m or ~5 m × 3.1/6.25 m (azimuth x range)	12 days (same geometry) †	Based on NISAR Availability
Disturbance Product (DIST)	_Near-Global**_	_Landsat 8 & Sentinel-2A/B (HLS)_	_DIST_ALERT_	30 m	16 days for Landsat 8 (same geometry) 10 days for Sentinel-2 (same geometry) ~5 days for Sentinel-2 (constellation + same geometry) median average 2.9 days for S2A/B+L8 [Li and Roy, 2017]	From the end of product validation: February 15, 2023
			_DIST_ANN_	30 m		
Dynamic Surface Water Extent (DSWx)	_Near-Global**_	_Landsat 8 & Sentinel-2A/B (HLS)_	_DSWx-HLS_	30 m	16 days for Landsat 8 (same geometry) † 10 days for Sentinel-2 (single sensor + same geometry) † ~5 days for Sentinel-2 (constellation + same geometry) † median average 2.9 days for S2A/B+L8 [Li and Roy, 2017]	From the end of product validation: July 15, 2022
		Sentinel-1A/B	_DSWx-S1_	30 m	12 days (single sensor + same geometry) † 6 days (constellation + same geometry) †	From the end of product validation: June 16, 2023
		NISAR	_DSWx-NI_	30 m	12 days (same geometry) †	From the end of product validation: February 6, 2024
		SWOT	_DSWx-SWOT_	TBD (100 m or 120 m)	21 days (same geometry) †	From the end of product validation: January 27, 2025

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[1] Temporal sampling of a pixel on the ground for a given product requires sensor ground simulations (TBD); hence, sensor sampling is provided.

*USA and U.S. Territories within 200 km of the U.S. border, Canada, and all mainland countries from the southern U.S. border up to and including Panama. **All landmasses, excluding Antarctica. ***Subjected to sensor availability. ****This indicates the beginning of the product record, not the beginning of OPERA processing. † Descending or Ascending.

3. 2. LEVEL 2 PRODUCTS

a. 2.1 Co-registered Single Look Complex (CSLC) Product

The CSLC product is derived from the range-Doppler radar-coordinate Single Look Complex (SLC) product using the Copernicus GLO-30 Digital Elevation Model (DEM) and orbit information of the relevant sensor, either Sentinel-1A/B or NISAR. The Sentinel-1 and NISAR CSLC products are independent products with separate co-registration processes and posting. For each sensor, the CSLC product is resampled to a fixed spatial reference grid and flattened, i.e., topographic phase contributions are removed. The CSLC contains individual raster layers representing complex signal return for each of the input dataset polarizations. The product metadata includes metadata from the input SLC product that allows for subsequent Interferometric Synthetic Aperture Radar (InSAR) processing, metadata related to the SLC co-registration processing algorithm used to generate the product, and metadata capturing the product geolocation grid. It is to be determined (TBD) if the CSLC is a radar-coded or geocoded product. If the CSLC products are provided as georeferenced products, native SLC resolution is preserved by generating the CSLC product with posting in east and north directions that are comparable to the full-resolution of the original input SLC (i.e., posting of CSLC-NI and CSLC-S1 will not be the same). If the CSLC products are provided in radar coordinates, a lookup table for the CSLC stack is provided for the geocoordinates. The products are stored in a cloud-compatible format that allows for subsetting. CSLCs from the same sensor can be combined to derive higher-level products such as displacement maps and surface-change maps. The spatial coverage of the CSLC products is over North America (USA and U.S. Territories within 200 km of the U.S. border, Canada, and all mainland countries from the southern U.S. border down to and including Panama).

For Sentinel-1A/B, the CSLC product is burst-based, whereas for NISAR-CSLC, the product is frame-based using the frame definition established by NISAR.

Tables 2.1 and 2.2 outline key product information as described in the high-level product description above. Note that these tables are *not* meant to be a product specification; see Section 1.2 for details on the scope of this Product Description Document.

Table 2.1: Product raster layers for CSLC.

CSLC Raster Layer	**Posting**	**Description**
Complex backscatter	Full resolution	SLC images for all polarizations resampled to a common grid. All channels are registered.
Secondary Layers Common to CSLC Stack	**Posting or Dimension**	**Description**
Slant range	TBD km scale, with the ability for users to recover it at approximately CSLC posting.	Geometry data layers
Incidence angle		
Line-of-Sight (LOS) vectors		

Table 2.2: Product metadata for CSLC.

CSLC Metadata Layer	**Description**
Input metadata	Input SLC file names and metadata that allows for subsequent InSAR processing (TBD)
Polarization	Baseline includes VV (vertical transmit and vertical receive) polarization for S1 and HH (horizontal transmit and horizontal receive) polarization for NISAR. TBD on funding/scope if this can be expanded to all polarizations from the input SLC product.
Processed range bandwidth	Signal range bandwidth
TBD: Azimuth Time and slant range information (if in radar coordinates) or geolocation grid information (if in geocoordinates)	The information for georeferencing. If geogrid information (coordinate system, pixel convention, spacing, map projection), Geographic Bounding Box
TBD: if in radar coordinates: look-up on geo-coordinates	
Sensor information	Left/right-looking, sensor name, wavelength, radar frequency
Processing information	Relevant processing parameters of the coregistration approach. References the Algorithm Theoretical Basis Document (ATBD) to allow users to trace and reproduce the process used for the specific product
Auxiliary information	DEM names, orbit files, aux files

b. 2.2 Radiometric Terrain-Corrected (RTC) Product

The RTC product is derived from the original Copernicus Sentinel-1A/B SLC data (Figure 1.1), provided by the European Space Agency, with a temporal product sampling coincident with the availability of Sentinel-1 A/B SLC data. The RTC product is not derived from the OPERA CSLC product as it has a different geographical scope (North America) compared to the RTC product (near-global) (see Table 1.3).

The workflow for generating the RTC product from Sentinel-1A/B consists of three steps. Sentinel-1A/B SLCs are first converted to radar brightness β_0 (beta naught) by applying absolute radiometric correction. The radar brightness has a strong dependency with the local topography. The radiometric terrain flattening or radiometric terrain correction (RTC) is then applied to each of the polarization channels at full resolution (single-look) to obtain the corresponding γ^0 (gamma naught) backscatter coefficient that has significantly less dependency with respect to the terrain (e.g., Small, 2011; Shiroma et al., 2022). Finally, the γ^0 backscatter is geocoded from the range-Doppler geometry to map coordinates through an adaptive multi-looking that accounts for the topography and radar geometry (Shiroma et al., 2022). The Copernicus GLO-30 DEM is used as the reference DEM for the RTC and geocoding.

In addition to the RTC product imagery, secondary layers including SAR geometric layers, layover/shadow mask, and RTC area normalization factor (or scattering area image TBD) are also provided. All relevant data and lookup tables are converted to map coordinates. The product metadata includes the input SLC metadata (e.g., processing parameters and orbit metadata); sensor information (left/right-looking, sensor name, wavelength, polarization, radar frequency); RTC processing information (algorithms and parameters); and product geolocation grid (including coordinate reference system and map projection).

The products and the metadata are stored in a cloud-compatible format for easy subsetting. As all RTC products are provided at the same reference grid, all the products over a given area can be analyzed in combination to derive higher-level products such as water extents (see Section 3, Level 3 Products). The spatial coverage of these products will be near-global (all landmasses excluding Antarctica). The RTC products are distributed as global tiles aligned with Harmonized Landsat Sentinel-2 (HLS) data.

Tables 2.3 and 2.4 outline key product information as described in the high-level product description above. Note that these tables are *not* meant to be a product specification; see Section 1.2 for details on scope of this Product Description Document.

Table 2.3: Product raster layers for RTC.

RTC Raster Layer	**Posting**	**Description**
Backscatter for each polarization	30 m	Linear units of γ^0 backscatter data
Secondary Layers	**Posting or Dimension**	**Description**
SAR geometric information including incidence angle (or TBD local incidence angle) and TBD (LOS unit vectors and ground track unit vectors)	2D rasters or 3D (TBD) metadata cubes with the ability for users to recover it at RTC posting	SAR geometric information
Mask	RTC posting	shadow, layover, water
RTC area normalization factor or scattering area image (TBD based on algorithm)	RTC posting	DEM-based area normalization factor or local contributing area image used for RTC correction

Table 2.4: RTC product metadata.

RTC Metadata Layer	**Description**
SLC input metadata	Input SLC file names, processing parameters (processed range and azimuth bandwidth, azimuth time information, slant range information), and orbit metadata
Sensor information	Left/right-looking, sensor name, wavelength, polarization, radar frequency
Geolocation grid information	The information for georeferencing (coordinate system, pixel convention, spacing, map projection)
Geographic Bounding Box	The four corners of the product file (bounding box) are identified, expressed in an accepted coordinate reference system
RTC processing information	Relevant processing parameters and algorithm information of the RTC processing approach to produce an RTC γ^0
DEM	DEM file name/link to the DEM used for radiometric terrain flattening
Processing information	RTC algorithm (e.g., bilinear distribution or area projection), RTC algorithm parameters, geocoding algorithm (e.g., nearest, bilinear, bicubic, biquintic, or sinc interpolation or area projection), and DEM interpolation algorithm.

	References the ATBD to allow users to trace and reproduce the process used for the specific product.

4. 3. LEVEL 3 PRODUCTS

a. 3.1 Displacement (DISP) Products

InSAR is a conventional remote sensing technique that exploits the phase difference between two repeat-pass SAR SLCs, acquired from the same sensor (e.g., NISAR or Sentinel-1), to measure anthropogenic and natural changes of Earth's surface (e.g., subsidence, tectonics, landslides). Regions with vegetation, agriculture, snow cover, wetlands, and the like that are prone to surface-scattering changes over time can introduce decorrelation noise in InSAR data (e.g., single SAR interferogram). Unlike conventional InSAR, time-series InSAR methods exploit a stack of co-registered SLC data to decrease the impact of decorrelation noise. These methods can be categorized into three groups: 1) Persistent Scatterer (PS) approaches, which are well-suited for urban areas; 2) Distributed Scatterer (DS) approaches, which are well-suited for rural locations; and 3) hybrid PS/DS approaches, which combine the advantages of both methods.

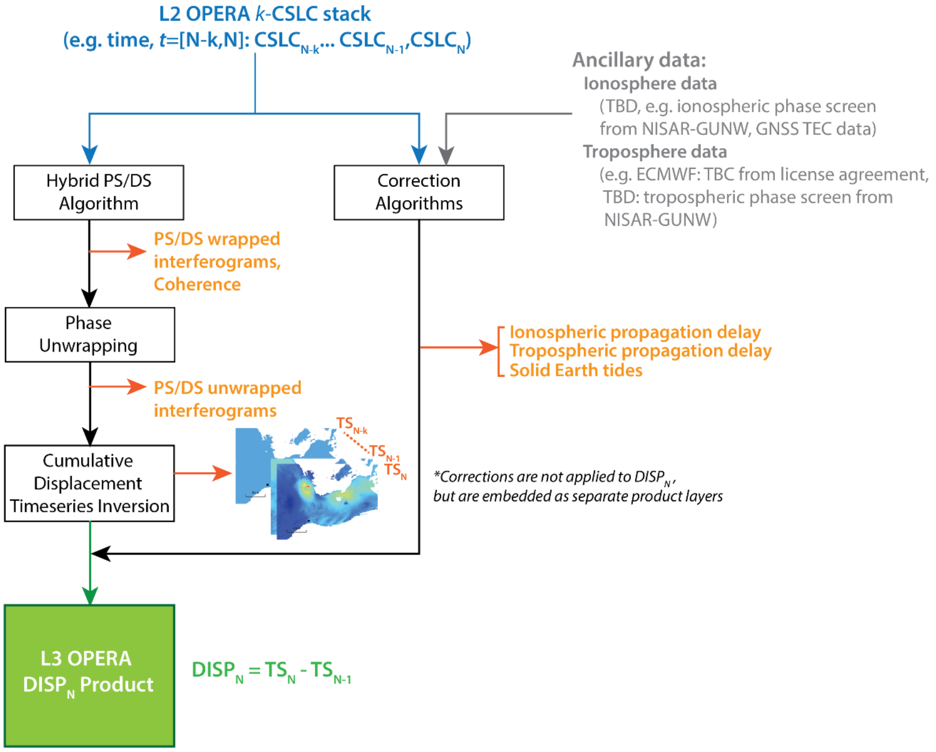
OPERA utilizes a hybrid PS/DS processing approach that uses the OPERA CSLC products as input data (Figure 1.1) and generates LOS displacement time series data as output (Figure 3.1a). NISAR and Sentinel-1 are processed up to a LOS displacement time series separately. As a new OPERA CSLC product becomes available for NISAR or Sentinel-1, their respective displacement time series is expanded. A DISP product distributed by OPERA corresponds to an individual time slice of the processed displacement time series, i.e., the surface displacements in the radar LOS between two sequential acquisitions. In order to produce DISP at the latest acquisition date (t=N) relative to the previous date (t = N-1), a stack of *k*-CSLCs (e.g., last *k*-CSLCs) are pulled for a time-series analysis from which only the differential estimated displacement between times N and N-1 will be archived. Users can sum consecutive DISP products to reconstruct the cumulative surface displacement time series over a given area, illustrated graphically in Figure 3.1c. Displacements are provided in metric units. Both the DISP-S1 and DISP-NI products – for Sentinel-1 and NISAR, respectively – are frame-based products. The Sentinel-1 and NISAR time series will provide complementing spatial-temporal information on ground displacements. DISP products from different satellite geometries (ascending or descending) and/or from NISAR and Sentinel-1 can be combined by users through application of data fusion or modeling approaches.

The DISP product metadata contains information on CSLC input products and their metadata for reproducibility, time-series processing information, and product geolocation grid. Additional qualitative data layers (e.g., the connected components from phase unwrapping), correction data layers (spatially correlated phase noise from tropospheric and ionospheric path delays, and solid Earth tides), and interferometric baseline data are included within each DISP product (Figure 3.2b). The correction layers are not applied to the data. SAR observation geometry (the incidence, azimuth, and heading angles), auxiliary processing files, and masks (water, shadow and layover) are included in the DISP products.

Tables 3.1 and 3.2 outline key product information as described in the high-level product description above. Note that these tables are *not* meant to be a product specification; see Section 1.2 for details on the scope of this Product Description Document.

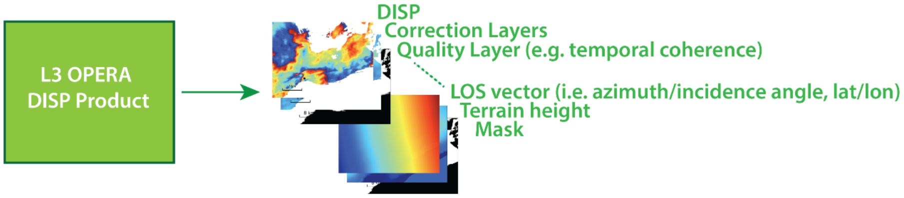
A)

To produce the OPERA DISP product at latest acquisition date (t=N):



B)

Each L3 OPERA DISP Product will contain several layers (*see Table 3.1*):



C)

Cumulative displacement timeseries, TS, can be reconstructed using sequential DISP products:

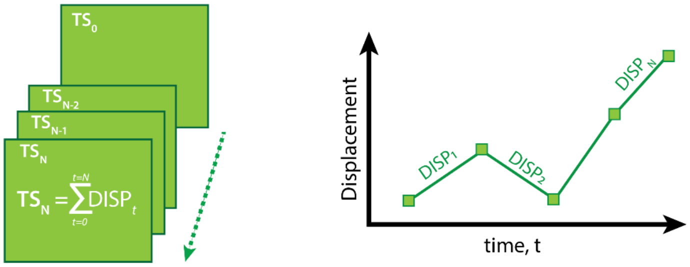


Figure 3.1: OPERA L3 DISP product description details. A) DISP product generated at latest acquisition date (t=N). ***Blue****:* input products; ***Gray****:* ancillary datasets; ***Orange****:* temporary products; ***Green****:* output product; ***Black****:* processing modules (details to be developed into ATBDs). B) Product raster layer for OPERA DISP as detailed in Table 3.1. C) End users to reconstruct the cumulative displacement time series using OPERA sequential DISP products.

Table 3.1: Product raster layer for OPERA DISP product.

DISP Raster Layer	**Posting**	**Description**
Displacement	30 m or approximately native sensor posting (TBD based on volume/cost estimates)	Displacement (metric units) for the HH polarization of the main band for NISAR and VV polarization for Sentinel-1
Connected Components		Connected components as metric for unwrapping quality
Quality		e.g., TBD: Temporal coherence (range 0 – 1) or other metic
(TBD on compute cost) Dense Offsets	TBD	Ground range and azimuth offsets (metric unit) to capture large ground displacements
(TBD on compute cost) Dense Offsets Quality Metrics		Quality metrics indicating the quality of the cross-correlation between the two SLCs
Ionosphere Delay	TBD, driven by resolution of the correction	Ionospheric propagation delay estimated from the data or from auxiliary information (Fattahi et al., 2017; Liang et al., 2019) (metric units)
Tropospheric Delay		Tropospheric propagation delays estimated from weather model data (Bekaert et al., 2021) (metric units)
Solid Earth Tides		Correction related to solid Earth tides (metric units)
Secondary Layer Common to DISP Stack	**Posting**	**Description**
losUnitVectors, (TBD on compute cost) Dense offset unit vectors	TBD, a low-resolution data cube as a function of height. Users can recover values at DISP posting through DEM intersection.	Unit vectors for LOS displacement and dense offset displacements
Incidence and azimuth angle, slantRange		Geometry information
Terrain height (TBD for volume considerations)	Same posting as the Displacement layer	Height layer, TBD if references directly to the source versus embedded in product for volume considerations
Mask		Flags for shadow, layover, water

Table 3.2: OPERA DISP product metadata.

DISP Metadata Layer	Description
SLC input metadata	Input CSLC files, polarization, bandwidth, azimuth time information, slant range information
Sensor information	Left/right-looking, sensor name, wavelength, radar frequency
TBD: Azimuth Time and slant range information (if in radar coordinates) or geolocation grid information (if in geocoordinates)	The information for georeferencing
TBD: If in radar coordinates, a lookup on geocoordinates	
Processing information	Algorithm processing parameters (e.g., used for time-series algorithm, ionosphere algorithm, tropospheric algorithm, solid Earth tide algorithm), and references to the ATBD to allow users to trace and reproduce the product using the OPERA open-source algorithm software
Auxiliary information	DEM names, orbit files, aux files, source for water mask, tropospheric model, solid Earth tides

b. 3.2 Dynamic Surface Water Extent (DSWx) Products

The DSWx suite of products maps the surface water extent on a near-global geographical scale (landmasses excluding Antarctica) with a temporal product sampling coincident with the availability of the optical and SAR input datasets (see Table 1.3). The DSWx product suite is not a harmonized product, as the harmonization algorithms were not deemed mature enough at the start of the OPERA DSWx product formulation. However, the DSWx products are structured to promote rapid synchronous analysis across the product suite and promote harmonization activities by the user community. All DSWx products share the same classification labels, grids, confidence layers, etc., allowing the community to rapidly compare sensor sensitivities and develop approaches for harmonization of the sensors for mapping surface water extent. The OPERA team will investigate harmonization as part of the project research activity and report important updates and findings as part of its Stakeholder Engagement Plan (SEP) outreach activities. A harmonized DSWx product may be infused in OPERA activities in a future augmentation of the project.

The DSWx suite is generated from optical (Harmonized Landsat-8 Sentinel-2A/B) and SAR (Sentinel-1A/B, NISAR, and SWOT) data, as summarized in Figure 1.1. Specifically, a separate DSWx product is generated for each input SAR dataset: for Sentinel-1 (DSWX-S1) from the OPERA RTC-S1 product, for NISAR (DSWx-NI) from the NISAR-produced-and-distributed NISAR RTC product, and for SWOT (DSWx-SWOT) using a TBD SWOT product. In the case of optical inputs, OPERA DSWx uses the Landsat Operational Land Imager and Sentinel MultiSpectral Instrument imagery harmonized and made available by NASA as Harmonized Landsat Sentinel-2 (HLS), hence DSWx-HLS. As this optical input data is harmonized prior to processing, the optical DSWx-HLS product has higher temporal sampling than water extent products derived from Landsat-8 or Sentinel-2A/B separately. This is an improvement upon existing available products. For example, while nearly global in extent, the Joint Research Center Global Surface Water Explorer products are only produced from Landsat, at monthly time steps, with a release frequency currently approaching annual (Pekel et al., 2016). The United States Geological Survey (USGS) Dynamic Surface Water Extent product is generated for each available Landsat scene and has latency nearing that targeted for DSWx but is also only over the United States. Ongoing USGS applications research has demonstrated the need for increased observation frequency, e.g., the development of techniques to estimate large Alaska river streamflow from satellite remote sensing. Such frequency would be facilitated first through DSWx production from the combined Landsat and Sentinel-2 observations provided by DSWx-HLS. DSWx-SAR (i.e., -S1 and -NI) observations are expected to augment the data record significantly, especially in cloud/low-sun incidence locations like Alaska.

DSWx products are distributed as tiles aligned with HLS tiles and are stored in a cloud-compatible format for virtual subsetting and data processing. The consistent gridding permits direct comparison across all DSWx products. Due to the varied nature of each input dataset, each DSWx product captures surface water extent and inundation with different levels of accuracy and uncertainty. For example, NISAR's L-band penetration into vegetation leads to larger estimates of inundated areas than Sentinel-1A/B, whose shorter wavelength leads to its signal's attenuation over such targets. The HLS products are more sensitive to cloud coverage and sun shadow, which are nonissues for SAR; however, SAR can suffer from layover and shadow issues in areas of steep terrain.

Collectively, the DSWx product suite will map the following water-related classes, even though products from one particular sensor may only detect a subset of these classes:

1. *Open water* – An area[2] 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.
3. *Inundated vegetation* – An area that contains vegetation and water, either partial surface water or open water.
4. *Obscured* – A mask that identifies an area as obscured by cloud or cloud shadow for the optical-derived products, and terrain or lay-over for the SAR-derived products.
5. *Not water* – An area that is **not** 1, 2, 3, or 4.

Note that *inundated vegetation* and *partial surface water* classes are **not** disjointed. For example, an area with sparse floating vegetation, from the definitions above, should be classified as both *partial surface water* and *inundated vegetation*. There are, however, areas that are distinctly *inundated vegetation* or *partial surface water*. A beach area containing only water and sand is classified strictly as *partial surface water,* while a water body occluded to the sensor entirely by vegetation is strictly *inundated vegetation*. The DSWx suite will not be responsible for differentiating these overlapping classes. Each product may exclude one of these overlapping classes given input dataset sensitivities. Specifically, the DSWx products will indicate the following:

- DSWx-HLS classes:
    - *Open water*
    - *Partial surface water*
    - *Not water*
    - *Obscured (by cloud or cloud shadow)*
- DSWx-NI classes:
    - *Open water*
    - *Inundated vegetation over wetlands:* TBD for inundated vegetation beyond wetlands. The project will perform a trade study to determine the feasibility and performance for retrievals beyond wetlands. The outcome of this study and potential change in scope will

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[2] An *area* may be the area of a pixel in an image.

    be discussed and integrated in a future version of this document (prior to releasing the baseline description for DSWx-NI).
  - *Not water*
  - *Obscured (by terrain shadow)*
- DSWx-S1 and DSWx-SWOT classes:
  - *Open water*
  - *TBD – Inundated vegetation over wetlands:* The project will perform a trade study to determine the feasibility and performance baseline of the DSWx-S1 and DSWx-SWOT products to detect inundated vegetation. The study will also include feasibility for retrievals beyond wetland locations. The outcome of this study and potential change in scope will be discussed and integrated in a future version of this document (prior to releasing the baseline description for DSWx-S1 and DSWx-SWOT).
  - *Not water*
  - *Obscured (by terrain shadow)*

While products from SAR and optical sensors may include different subsets of classes, the class labels will be *consistent across the entire DSWx suite*. Having consistent classification labels across the suite will be invaluable for data fusion and harmonization of the DSWx-suite by end users. For example, it will be possible to quantify the overlap of the inundated vegetation from DSWx products from SAR inputs with partial surface water from the DSWx-HLS products to further elucidate the type of inundation present in a particular pixel.

The DSWx suite includes three primary layers that are shared across *all* of the products:

5. Water classification labels (WTR) – This represents pixel-wise classification into one of the four water classes listed above (each product will map to a strict subset of three of the classes). Masks (for the HLS data) are applied indicating where valid data is retrieved. As mentioned previously, the classification labels will be shared across all the datasets for rapid synchronous analysis.
6. Binary water layer (BWTR) – This is a union of water classes (open water, inundated vegetation, partial surface water) in a binary map indicating areas with and without water. This is meant to provide users with a quick view for water/no-water.
7. (TBD) Confidence layer (CONF) – This assigns a number in the half-open interval (between 0 and 100) to the confidence of the classification label. Each product will assign a confidence value to the WTR label and will be consistently applied throughout each DSWx product. Additional analysis may be required to compare this confidence value across the DSWx suite but could potentially be useful for harmonization activities in the future.

There are additional layers for each product, but the above represent the core of the DSWx product suite, particularly those that are relevant for future harmonization activities. Figure 3.2 shows a sample binary water layer from the USGS Dynamic Surface Water Extent (DSWE). (This product is the predecessor of the DSWx-HLS product, and much of the algorithm is derived from this scientific work.)

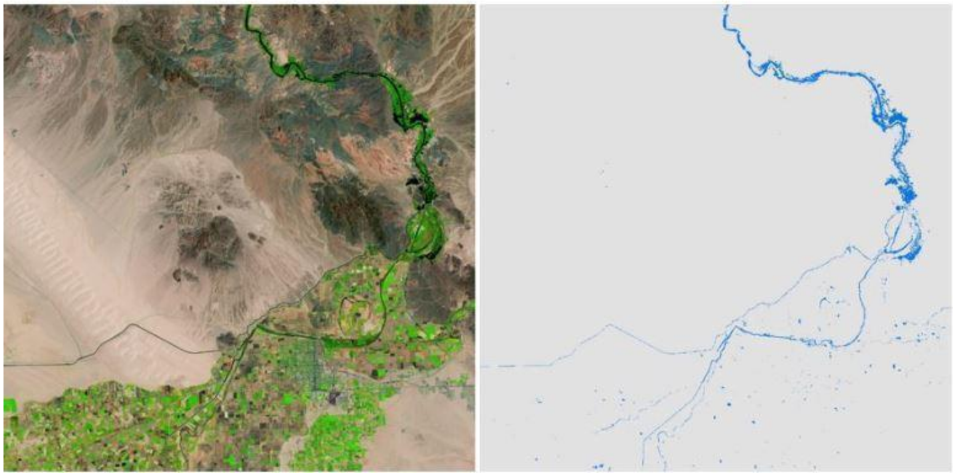

Figure 3.2: Side-by-side images over an area northeast of Yuma, AZ, of a Landsat Surface Reflectance Analysis Ready Data (ARD) tile (left) and a Landsat Level-3 DSWE image (right), reclassified to a binary "water/not water" layer (see Table 3.3). Both images are derived from Landsat 7 ARD Tile Horizontal 005, Vertical 013, collected August 16, 2000. The images are in the public domain and taken from the USGS DSWE site.

All the DSWx products from optical (Table 3.3) and SAR (Table 3.4) will share similar metadata layers, as described in Table 3.5. Tables 3.3 through 3.5 outline product information as described in the high-level product description above. These tables are *not* meant to be a product specification; see Section 1.2 for details on the scope of this Product Description Document.

For the optical DSWx-HLS, there are additional intermediate layers, which are summarized in Table 3.4. In addition to the detailed classification labels (WTR), the DSWx-HLS product provides nuanced land cover classification, cloud cover data, and intermediate water extent maps. These additional layers allow users to employ customized cloud and/or shadow masks in place of those distributed with the original input HLS data (Claverie et al., 2018), which are used to create the DSWx-HLS WTR result.

Three relevant masks are utilized to create these intermediate layers. These mask layers are derived from input HLS data and auxiliary datasets: land cover classification (e.g., USGS/Multi-Resolution Land Characteristics Consortium), a shaded relief–based terrain shadow mask (SHAD), and a cloud classification (distributed with the HLS input dataset [Claverie et al., 2018]). The land cover and cloud layers will be called LAND and CLOUD, respectively.

The diagnostic layer (DIAG in Table 3.3), which is the result of five tests applied to each pixel of the HLS input, is initially interpreted into water classes as in Jones (2019) and USGS DSWE without any additional land cover testing or cloud masking applied. The result is named WTR-0. This result is refined through comparison with land cover (LAND) and topographic shadow information (SHAD) to produce a secondary layer (WTR-1). Finally, the primary WTR layer is derived from WTR-1 after masking using CLOUD. The provision of intermediate layers allows advanced users to incorporate more detailed land cover maps and cloud masks to generate related products for their areas of interest.

For the SAR suite, the layers are fewer with only the three core layers (discussed above). More layers may be determined depending on the algorithm flowdown. The classes for BWTR will be open water, inundated vegetation, and not water, as discussed above, although the class labels will be consistent with the entire DSWx suite.

Table 3.3: Product raster layer for DSWx-HLS.

DSWx Raster Layer	**Posting**	**Description**
Water classification (WTR)	30 m	Classification into open water, partial surface water, inundated vegetation, and no-water. Masked layers are applied so that no data areas cover masked inputs and original no-data pixels of the input dataset.
Binary Water (BWTR)		Binary water map with all water classes (open water, partial surface water, and inundated vegetation) combined. Derived from the above interpreted layer.
TBD Confidence (CONF)		Confidence in the prescribed classification. Value in the half-open interval between 0 and 100.
Detailed water classification applied to raw HLS data (WTR-1)		This is the intermediate classification in which the classification is applied directly to the input HLS dataset.
Detailed water classification with additional land cover testing (WTR-2)		Classification into open water, partial surface water, and no-water with additional land cover testing as described in Jones (2019).
Diagnostic (DIAG)		A layer coded to indicate which of the five DSWE tests were positive for water detection on a per-pixel basis. The tests are described in Jones (2019) and are used to derive the Confidence layer. The percentage of positive tests for a particular class determines its confidence value.
Cloud classification (CLOUD)		Cloud, cloud shadow, and snow classifications transferred from HLS input.
Land cover classification (LAND)		Land cover classification used for the intermediate layer WTR-2 and WTR.
Shadow layer (SHAD)		Location and image capture date/time-specific shaded relief used for HLS-based product masking. This is used for optical processing of the HLS inputs.
Secondary Layers Common to DSWx Stack	**Posting**	**Description**
Height above nearest drainage (HAND)	30 m	Height above nearest drainage (Nobre et al., 2011); heuristic layer indicative of likelihood of pixel being a water pixel.
DEM Height		Height of reference DEM.

Table 3.4: Product raster layer for SAR DSWx products (DSWx-S1, DSWx-NI, and DSWx-S1).

DSWx Raster Layer	**Posting**	**Description**
Detailed water classification (WTR)	30 m (TBD for SWOT)	Classification into open water, inundated vegetation, and no-water. No data areas match the input datasets and any additionally masked areas. For Sentinel-1 and SWOT, the detection of inundated vegetation is pending a trade study by the project to determine the feasibility and performance baseline.
Binary Water (BWTR)		Binary water map with all water classes (open water, partial surface water, and inundated vegetation) combined. Derived from the above interpreted layer.
Confidence (CONF)		Model confidence for each classification between 0 and 100 .
Secondary Layers Common to DSWx Stack	**Posting**	**Description**
Height above nearest drainage (HAND)	30 m (TBD for SWOT)	Height above nearest drainage (Nobre et al., 2011); heuristic layer indicative of likelihood of pixel being a water pixel, used for DSWx SAR processing.
DEM Height		Height of reference DEM.

Table 3.5: DSWx product metadata across the suite.

DSWx Metadata	**Description**
Input image metadata	Image (i.e., HLS Sentinel-2A/B or Landsat 8 for DSWx-HLS, Sentinel-1A/B, etc.) input tiles' names, sensor name, time information.
Processing algorithm information	References the ATBD and algorithm-specific parameters to allow users to trace and reproduce the process used for the specific product.
Geolocation grid information	The information for georeferencing (coordinate system, pixel convention, spacing, map projection) aligned with HLS tiles.
Geographic bounding box	Bounding box expressed in an accepted coordinate reference system.
Auxiliary information	Aux files needed for processing.

a.

b. 3.3 Disturbance (DIST) Product

The DIST product maps per-pixel vegetation disturbance (specifically, vegetation-cover loss) from the Harmonized Landsat-8 and Sentinel-2A/B (HLS) scenes. Vegetation disturbance is mapped when there is an indicated decrease in vegetation cover within an HLS pixel. The product also provides auxiliary generic disturbance information as determined from the variations of the reflectance through the HLS scenes to provide information about more general disturbance trends. The DIST product suite is composed of two products according to their temporal scope: 1) the DIST_ALERT product, which is released at the cadence of HLS imagery, and 2) the DIST_ANN product, which summarizes the DIST_ALERT product, specifically confirmed changes, from the previous year. The interannual comparisons used to identify areas of disturbance, the definition of vegetation-cover loss, the types of disturbances that can be detected by the DIST product, how a disturbance is confirmed, and the relationship between DIST_ALERT and DIST_ANN are detailed below.

To define vegetation disturbance, first vegetation cover and its loss must be defined. Cover (as in "vegetation cover") is defined as "the amount of skylight orthogonal to the surface that is intercepted by the cover trait of interest" (Carrol et al., 2010). In relation to the DIST product, vegetation includes all plant life over land, including woody and herbaceous (i.e., non-woody), as is done for the Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Continuous Field (VCF) product (Hansen et al., 2003; Zhan et al., 1999). Vegetation loss within a pixel over a given time frame is defined to be 50% vegetation cover decrease when the scene is compared to the previous calendar years, as in Ying et al. (2017). The number of calendar years for this comparison will depend on HLS availability and be determined during algorithmic calibration, as detailed in the ATBD.

The DIST product suite identifies disturbances in vegetation cover from prior years by comparing each current HLS scene to a composite from previous years representing a lower bound of observed vegetation cover. The composite is derived from a small temporal window around the date of the current HLS scene to account for intra-annual variation. The number of scenes used to generate the composite for interannual comparison will be determined during the algorithm calibration and detailed in the ATBD as well as future versions of this document. Figure 3.3 illustrates a hypothetical time series through an HLS pixel. Specifically, this time series is meant to illustrate how comparisons are made: Each HLS scene compares vegetation cover to previous years, factoring in intra-annual variability to determine a 50% vegetation cover loss.

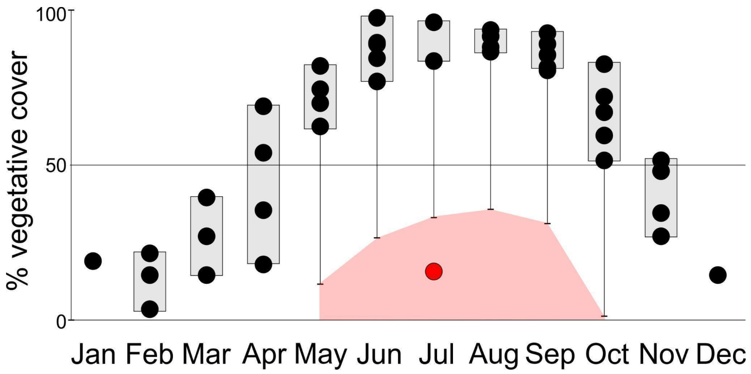

Figure 3.3: Example illustration for an HLS pixel (from RD2). The time series of historical vegetation cover estimates from HLS scenes of previous years are represented by black circles, and the gray boxes

represent the range. The pink area represents the range of current-year vegetation-cover estimates that would result in a vegetation disturbance alert with an anomaly of ≥50%. The red circle is an example of a current-year observation from July that would be marked as vegetation disturbance.

The vegetation disturbances detected by the DIST vegetation disturbance product do *not* include *all* land disturbances or all vegetation changes, for that matter – only disturbances that are a result of vegetation cover loss with respect to interannual comparison. Forest loss, fire scars across vegetated landscapes, sick or dying vegetation reducing photosynthetic activity, urban development of vegetated areas, vegetated sandbar erosion, and mining impacts atop vegetated areas *are detected* by the vegetation-disturbance status layer of the DIST product (see examples in Figure 3.4). Landslide extents can also be identified if landslide material (e.g., rock, soil, and sediment) covers a previously vegetated area or if a landslide creates a hillslope scar. Some land disturbances *are not detected* by the vegetation disturbance layer, including vegetation *recovery*; phenological and intra-annual vegetation changes; urban development within urban sprawl (e.g., buildings being replaced or demolished); and more generally, any urban changes of non-vegetated areas (e.g., a highway built over a desert landscape); lava flows over rocky, non-vegetated terrain; crop rotations; and disturbance of non-photosynthetic vegetation. Further, if fire scars are part of *regular* local conservation and management (e.g., annual burns of savanna grasslands in Zambia [Eriksen, 2007]), the vegetation loss and fires scars will not be detected, as such disturbances are within the normal interannual variability.

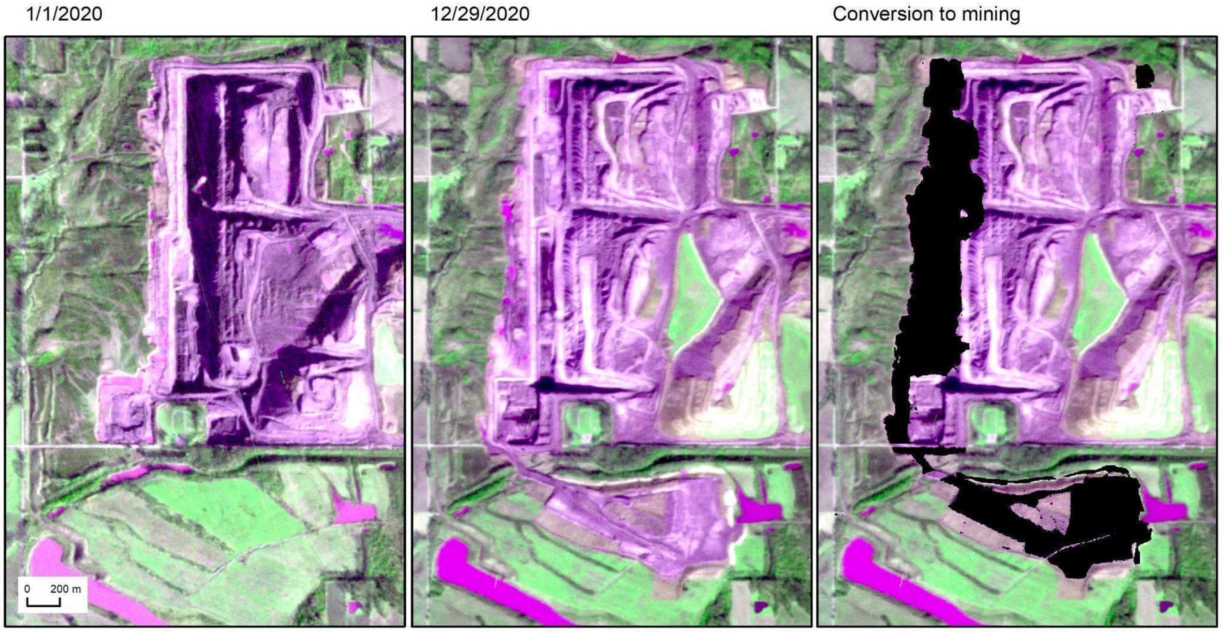

Figure 3.4: Examples of vegetation disturbances that are captured in the DIST product suite (images from PlanetScope, false color composite of Red-NIR [near-infrared]-Green). Here, vegetation is characterized by shades of green and gray, and bare ground by shades of pink. In the final column, black represents areas of conversion. Top row: Vegetation conversion to mining in Indiana. Bottom row: Vegetation conversion to urban development in Dallas, TX. From RD2.

For generic disturbance analysis, the DIST product records the variation of the HLS reflectances from the interannual norm. The variation is measured using the Euclidean distance (or L_2-norm) when viewing the reflectances as a real-valued vector. As in the case for vegetation disturbance, each current HLS scene is compared to a historical composite derived from previous calendar years. Although a single historical composite value cannot be reported given multiple reflectances within an HLS scene, the current HLS scene's distance to the composite's reflectance is recorded within DIST layers. Generic disturbances are meant to provide additional, qualitative outliers with respect to all the HLS reflectance time series. However, no disturbance category is determined for these generic disturbances, and they only provide an expedient means to identify outliers within the HLS time series.

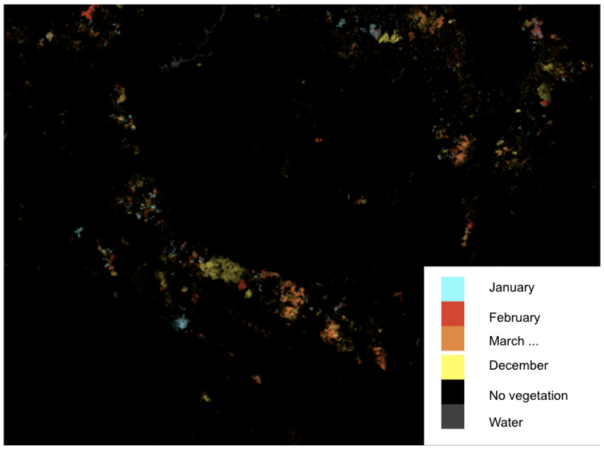

Figure 3.5: A hypothetical DIST product in which vegetation loss and the month of first detection are shown (modified and derived from Hansen et al. [2013]). In the DIST product, the precise Julian date is recorded.

Two DIST products are generated within the DIST product suite with respect to their temporal relevance: 1) the DIST_ALERT product, capturing vegetation disturbance at the cadence of HLS sampling (median average 2.9 days for S2A/B+L8 [Li and Roy, 2017]); and 2) the DIST_ANN product, summarizing changes of the DIST_ALERT products from the previous year. The date of the first disturbance is tracked within both products. Each DIST_ALERT product is associated with an HLS scene and is used to track vegetation disturbances at the temporal frequency of the input HLS dataset. The DIST_ANN tracks changes at the annual scale, aggregating changes identified in the DIST_ALERT product.

This vegetation disturbance is delineated within the *vegetation disturbance status* layer in the DIST product suite (see Tables 3.6 and 3.8). The DIST_ALERT product tracks two categories of disturbances: *provisional* and *confirmed* (for both ≥50% and <50% estimated vegetation-cover loss). *Provisional disturbances* are when a pixel is first identified to have vegetation-cover loss and *confirmed disturbances* are when this disturbance is identified consistently through some number of subsequent acquisitions in time. The precise number of scenes required for a *confirmed* status will be determined during the algorithmic calibration and detailed in the ATBD. If a pixel marked *provisional disturbance* has no observed loss in subsequent images, then this label will be removed and this pixel's vegetation cover will continue to be analyzed for future vegetation-cover losses. In DIST_ANN, only *confirmed disturbances* from the associated year are reported together with the date of initial disturbance. *Confirmed disturbances* are determined after subsequent cloud-free observations over the target, which may require *more* HLS scenes depending on the visibility of the target. Due to this, summarizing the DIST_ALERT in the DIST_ANN product will have some latency depending on the algorithmic calibration, which will be detailed in subsequent documentation. Additional contextual layers are provided for disturbed pixels, including the date of initial disturbance, vegetation disturbance confidence, number of observed anomalies (defined below), and disturbance duration.

In addition to disturbance status, for every HLS scene an estimate of the current percent vegetation cover and the current anomaly value are provided within the DIST_ALERT product. The anomaly value is defined as the difference in estimated percent vegetation cover between the seasonally normalized lower bound of historical vegetation cover (historic vegetation cover indicator) and the percent vegetation cover estimate from the current HLS scene. Only anomalies of vegetation loss are reported, but within this, the full range of 1–100% loss is reported. Given potential rapid vegetation recovery, the anomaly value corresponding to the date of maximum anomaly as well as the historical lower bound from that date are reported. As the historical lower bound corresponds to the date of maximum anomaly, it is not reported for pixels without recorded anomalies. The vegetation-cover estimate for the current year at the date of maximum anomaly can be calculated from these two values.

Although disturbances must be reported for ≥50% vegetation-cover loss per the project requirements and validation activities, smaller-scale disturbances are also included. Additional DIST layers (see Tables 3.6 and 3.8) can be leveraged to assess the magnitude and duration of these disturbances. Specifically, within the DIST product, a number of layers capture vegetation indicators (see Tables 3.6 and 3.8) that are correlated with vegetation cover. The statistical relationship of these layers with vegetation cover will be documented through validation activities and released after the DIST validation period. Figure 3.6 shows the MODIS VCF to illustrate how the vegetation indicator layers will be correlated.

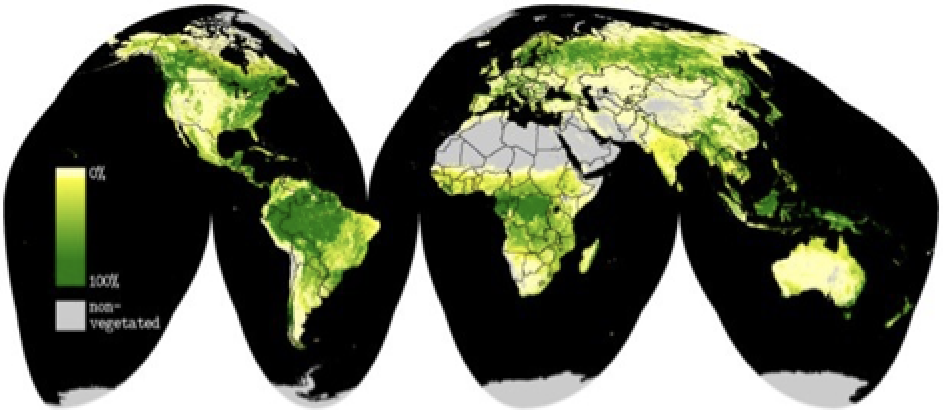

Figure 3.6: The MODIS VCF provides a validated vegetation cover estimate (Hansen et al., 2003). The DIST product will provide a current vegetation indicator layer that will be correlated with vegetation cover.

Although measuring vegetation cover is beyond the scope of the DIST product, these auxiliary vegetation indicator layers that are used by the internal models for identifying areas of disturbance can be used for additional correlative analysis directly. For example, the *maximum vegetation anomaly* can be harnessed to set a threshold for vegetation cover loss at a higher sensitivity (i.e., loss <50%), and the *current vegetation cover indicator* can be tracked over time to evaluate possible recovery trends. Additional layers related to the vegetation indicator are described in Tables 3.6 and 3.8.

In the annual summary of DIST_ANN, the historic vegetation cover indicator and anomaly value corresponding to the date of maximum anomaly from that year are provided for confirmed disturbance pixels. Additionally, the vegetation cover from that year is summarized by the maximum estimated percent vegetation for all non-disturbance pixels and the estimated percent vegetation cover at the date of maximum anomaly for all confirmed disturbance pixels. In Figure 3.6, the MODIS VCF global vegetation map providing a per-pixel estimate of maximum percent green vegetation cover is shown (for DIST_ANN, a similar map is created from all HLS scenes of the given year with disturbed pixels, instead having the percent vegetation cover estimate of the date of maximum anomaly). We note that the vegetation cover is a qualitative layer, in that the vegetation covers are not formally validated via requirements (only the *vegetation disturbance status layers* are).

Input metadata, disturbance time-series processing information, product geolocation grid, and data-quality flags such as the employed land mask are included. DIST products are distributed aligned with the HLS input products. The rasters will be stored in a cloud-compatible format for easy subsetting. The DIST products are generated over a near-global scope (all landmasses excluding Antarctica and Greenland). Tables 3.6 and 3.7 outline key product information for DIST_ALERT, as described in the high-level product description above, and similarly, Tables 3.8 and 3.9 outline the same for DIST_ANN. These tables are *not* meant to be a product specification; see Section 1.2 for details on scope of this Product Description Document.

Table 3.6: Product raster layer for DIST_ALERT.

DIST Raster Layer	Posting	Description
Vegetation disturbance status	30 m	Indication of vegetation cover loss (vegetation disturbance). Four possible categories of vegetation disturbance: “provisional ≥50%,” “confirmed ≥50%,” “provisional <50%,” and “confirmed <50%.” The label “provisional” is used when disturbance is first detected, and “confirmed” is used when vegetation disturbance is detected for a consecutive number of HLS scenes.[1] These labels are reported for both above and below the 50% disturbance threshold.
Current vegetation cover indicator (TBD)		The percent vegetation cover estimated for the current HLS scene for all land pixels.
Current vegetation anomaly value		Difference between historical and observed vegetation cover at the current date (vegetation loss of 0–100%). The sum of this anomaly value and the current vegetation cover indicator will be the historical vegetation-cover estimate.
Historical vegetation cover indicator		Historical percent vegetation cover proxy from composite of HLS scenes during the same time period of the maximum anomaly for disturbance pixels. A fill value is used for all non-disturbance pixels. Historical vegetation is calculated from a synchronous temporal window from previous calendar years to capture intra-annual/seasonal variation.[2]
Max vegetation anomaly value		Difference between historical and current year observed vegetation cover at the date of maximum decrease (vegetation loss of 0–100%). The sum of the historical percent vegetation and the anomaly value will be the vegetation-cover estimate for the current year. This layer can be used to set a threshold for vegetation disturbance per a given sensitivity (e.g., disturbance of ≥20% vegetation-cover loss).
Vegetation Disturbance Confidence Layer		Sum of the differences of vegetation fraction since initial anomaly detection times the number of loss anomalies, until the anniversary date is reached, or a fixed number of consecutive non-anomalies are observed.
Date of initial vegetation disturbance		Julian day of first loss anomaly detection, if applicable.
Number of detected vegetation loss anomalies		Total number of loss anomalies for confirmed disturbances.
Vegetation disturbance duration		Number of days of ongoing loss anomalies since initial anomaly detection.
Generic disturbance anomaly value (TBD)	30 m	Euclidean distance between current HLS scene reflectance and the composite reflectance of previous calendar years.[3]
Generic disturbance maximum anomaly value (TBD)		Maximum Euclidean distance between a current year HLS scene reflectance and the composite reflectance of previous calendar years.[3]
Date of last valid land observation	30 m	Julian day of last quality assessed/passed HLS observation

DIST Raster Layer	Posting	Description
Land mask		Mask of pixels the vegetation disturbance algorithm is applied to in the current HLS scene. Adapted from methods described in Potapov et al. (2020).

[1] The precise number of scenes required for a "confirmed" status will be detailed in the ATBD.
[2] The precise statistical compositing methodology will be detailed in the ATBD.
[3] The precise statistical compositing methodology will also be determined during calibration and detailed in the future ATBD.

Table 3.7: DIST_ALERT product metadata.

DIST Metadata Layer	Description
Input image metadata	Image (i.e., HLS Sentinel-2A/B or Landsat 8) input tiles' names, sensor name, time information
Processing algorithm information	References the ATBD to allow users to trace and reproduce the process used for the specific product. Parameters used in heuristical time series modeling.
Geolocation grid information	The information for georeferencing (coordinate system, pixel convention, spacing, map projection), tiling aligned with HLS dataset.
Geographic bounding box	Bounding box expressed in an accepted coordinate reference system.

Table 3.8: Product raster layer for DIST_ANN.

DIST Raster Layer	Posting	Description
Vegetation disturbance status	30 m	Status of confirmed disturbance, current provisional disturbance, and no disturbance.
Historical vegetation cover indicator		Historical percent vegetation from composite of HLS scenes during the same time period of the maximum anomaly for disturbance pixels. A fill value is used for all non-disturbance pixels. Historical vegetation is calculated from a synchronous temporal window from previous calendar years to capture intra-annual/seasonal variation.[1]
Vegetation cover indicator		For non-disturbance pixels, maximum annual vegetation fraction from the HLS time-series data will be reported. For disturbance pixels, the vegetation fraction from the date of maximum anomaly will be reported.
Maximum vegetation anomaly value		Difference between historical vegetation cover and vegetation cover at the date of maximum decrease (vegetation loss of 0–100%). The sum of the global vegetation fraction at the date of maximum anomaly and the anomaly value will provide the previous vegetation-cover estimate at the time of maximum fractional vegetation loss. This layer can be used to set a threshold for vegetation disturbance per a given sensitivity (e.g., disturbance of ≥20% vegetation cover loss).
Vegetation Disturbance Confidence Layer		Sum of the differences of vegetation fraction since initial anomaly detection times the number of loss anomalies, until the anniversary date is reached, or a fixed number of consecutive non-anomalies are observed.[2]

DIST Raster Layer	Posting	Description
Date of initial vegetation disturbance		Julian day of first loss anomaly detection, if applicable.
Number of detected vegetation anomalies		Total number of loss anomalies for confirmed disturbances.
Vegetation disturbance duration		Number of days of ongoing loss anomalies since initial anomaly detection.
Generic maximum disturbance anomaly value (TBD)	30 m	Max euclidean distance between the reflectance of an HLS scene within the year and the composite reflectance of previous calendar years.[3]
Date of last valid land observation	30 m	Julian day of last quality assessed/passed HLS observation

[1] The precise number of scenes required for "confirmed" status will be detailed in the ATBD.

[2] The precise statistical compositing methodology will be detailed in the ATBD.

[3] The precise statistical compositing methodology will also be determined during calibration and detailed in the future ATBD.

Table 3.9: DIST_ANN product metadata.

DIST Metadata Layer	Description
Input image metadata	Image (i.e., HLS Sentinel-2A/B or Landsat 8) input tiles' names, sensor name, time information
Processing algorithm information	References the ATBD to allow users to trace and reproduce the process used for the specific product. Parameters used in heuristical time series modeling.
Geolocation grid information	The information for georeferencing (coordinate system, pixel convention, spacing, map projection), tiling aligned with HLS dataset.
Geographic bounding box	Bounding box expressed in an accepted coordinate reference system.

8. ACRONYMS

Acronym	**Definition**
AD	Applicable Document
ADT	Algorithm Development Team
ARD	Analysis Ready Data
ATBD	Algorithm Theoretical Basis Document
BWTR	Binary Water (Layer)
CARD4L	CEOS Analysis Ready Data for Land
CEOS	Committee on Earth Observation Satellites
CLOUD	Cloud (Classification)

CONF	Confidence (Layer)
CSLC	Co-registered Single Look Complex (Product)
DAAC	Distributed Active Archive Center
DEM	Digital Elevation Model
DIAG	Diagnostic (Layer)
DISP	Displacement (Product)
DIST	Disturbance (Product)
DIST_ALERT	Disturbance Alert (Product)
DIST_ANN	Annual Disturbance Summary (Product)
DS	Distributed Scatterer
DSWE	Dynamic Surface Water Extent (USGS Product)
DSWx	Dynamic Surface Water Extent (Product)
ECMWF	European Centre for Medium-Range Weather Forecasts
EOSDIS	Earth Observing System Data and Information System
EPSG	European Petroleum Standards Group
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
HAND	Height above Nearest Drainage
HH	Horizontal Transmit and Horizontal Receive
HLS	Harmonized Landsat Sentinel-2 (Input Product)
InSAR	Interferometric Synthetic Aperture Radar
JPL	Jet Propulsion Laboratory
L1, L2, L3, etc.	Level 1, Level 2, Level 3, etc.
LAND	Land Cover (Classification)
LOS	Line-of-Sight
LULC	Land Use and Land Classification
LUT	Lookup Table
MODIS	Moderate Resolution Imaging Spectroradiometer
NIR	Near-Infrared
NISAR or NI	NASA-ISRO SAR (Mission)
OPERA	Observational Products for End-Users from Remote Sensing Analysis
PS	Persistent Scatterer
PST	Project Science Team

RD	Reference Document
RTC	Radiometric Terrain-Corrected (Product), or Radiometric Terrain Correction
SAR	Synthetic Aperture Radar
SDS	Science Data System
Sentinel-1 or S1	Sentinel-1A/B (Mission)
Sentinel-2 or S2	Sentinel-1A/B (Mission)
SEP	Stakeholder Engagement Plan
SHAD	Shadow (Layer)
SLC	Single Look Complex
SNWG	Satellite Needs Working Group
SWOT or SW	Surface Water and Ocean Topography (Mission)
TBD	To Be Determined
U.S. or USA	United States of America
USGS	United States Geological Survey
VCF	Vegetation Continuous Field
VV	Vertical Transmit and Vertical Receive
WTR	Water (Classification)