Surface Water and Ocean Topography (SWOT) Project

Algorithm Theoretical Basis Document

Long Name: Level 2 High Rate Raster Science Algorithm Software
Short Name: L2_HR_Raster

Revision A (DRAFT)

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See Sect 1.5 for how to cite this document

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CHANGE LOG

VERSION	DATE	SECTIONS CHANGED	REASON FOR CHANGE
Initial Release (DRAFT)	2023-06-05	ALL	Initial Release (DRAFT) Approved for export (LRR-073022)
Initial Release	2023-09-18	ALL	Initial Release Approved for public release (URS319736/CL23-5145)
Revision A (DRAFT)	2024-09-24	ALL	Revision A (DRAFT) Updated height-constrained geolocation smoothing method (Sections 3.1 and 2.2) Updated references to "L2_HR_PIXC samples" and "L2_HR_Raster pixels" for clarity Minor edits

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1 Introduction

1.1 Purpose

The purpose of this Algorithm Theoretical Basis Document (ATBD) is to describe the physical and mathematical basis for the science data processing algorithms that are used to generate the Level 2 Ka-band Radar Interferometer (KaRIn) high-rate (HR) raster data product from the Surface Water Ocean Topography (SWOT) mission. This data product is also referenced by the short name L2_HR_Raster.

This document describes algorithms used for both operationally processed and on-demand versions of the L2_HR_Raster product as described in [1].

1.2 Scope

The scope of this document is to:

1. Identify the list of primary functions that compose the Level 2 processing steps and their flow. These functions are broken down by the primary functional steps involved in the processing.
2. Describe the purpose of each of the functions.
3. Describe the input data to each function.
4. Describe the output data from each function.
5. Describe the mathematical basis of the algorithm in each function.
6. Describe the expected accuracy and/or limitations of the algorithm in each function.
7. Provide the relevant references for the algorithms described in this document.

1.3 Document Organization

Section 2 provides the background and context of the algorithms described in this document, and the functional flow of the primary functions (e.g., block diagram).

Section 3 provides the algorithm description for each of the functions shown in the block diagram, including input data, output data, mathematical basis, and expected accuracy.

Section 4 provides references for the algorithms described in this document.

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

1.4 Document Conventions

Where specific names of data variables and groups of the data product are given in the body text of this document, they are usually represented in italicized text.

Where the names of specific internal variables of the processing are not particularly relevant to the algorithm description, this document often refers to the L2_HR_Raster SAS (science algorithm software) in reference to software variables containing information that goes into or comes out of different algorithm functions.

1.5 Citing This Document

Please cite this document as follows:

> JPL D-105507, "SWOT Algorithm Theoretical Basis Document: Level 2 KaRIn High Rate Raster (L2_HR_Raster) Science Algorithm Software," Jet Propulsion Laboratory Internal Document, 2024.

2 Overview

2.1 Background and Context

This document describes the Level 2 processing steps that are used to generate the L2_HR_Raster product. The L2_HR_Raster product contains rasterized water surface elevation (WSE) and inundation extent data from the HR data stream of the KaRIn instrument, along with appropriate uncertainties and flags, resampled onto a uniform grid. A uniform grid is superimposed onto the pixel cloud from the L2_HR_PIXC [2] and L2_HR_PIXCVec [3] products, and all L2_HR_PIXC samples within each grid cell are aggregated to produce a single value per raster cell. A description of the L2_HR_Raster product is provided in [1].

2.2 Functional Flow

Table 1 provides a high-level description of each of the Level 2 processing functions that are used to generate the L2_HR_Raster product. Figure 1 then illustrates the high-level processing steps, and Figure 2 illustrates the lower-level rasterization processing steps.

The L2_HR_PIXC and L2_HR_PIXCVec products serve as the source for generating the L2_HR_Raster product. The L2_HR_Raster processing first updates the geolocated locations of the L2_HR_PIXC samples using a height-constrained geolocation approach, and then aggregates measurements from the input files into coarser resolution and sampling to reduce measurement noise.

The L2_HR_Raster processor additionally supports a number of on-demand processing options. These on-demand options command user specified granule extents, resolutions, and output coordinate reference system specifications. The available on-demand options only modify the coordinate reference system and sampling grid of the output data, and do not change the measurement aggregation algorithms. The parameters that can be specified in on-demand processing are supplied to the algorithms via a run-time configuration file.

Table 1. High-level description of the functions used to generate the L2_HR_Raster product.

Function Name	Description
do_smoothed_slant_plane_hc_geoloc	Smooths pixel cloud heights for interferogram flattening and height-constrained geolocation and performs height-constrained geolocation.
do_raster_processing	Generates a raster image
create_projection_from_polygon_points	Generates the output projection information from a polygon defining the extent of the L2_HR_Raster scene and the run-time configuration parameters
get_raster_mapping	Maps L2_HR_PIXC samples to the raster coordinate reference system.
get_rasterization_masks	Generates masks indicating which L2_HR_PIXC samples to aggregate for each L2_HR_Raster pixel.
aggregate_cross_track_and_incidence_angle	Aggregates the signed cross track distance and incidence angle for each L2_HR_Raster pixel.
aggregate_illumination_time	Aggregates the time of illumination of each pixel (UTC and TAI) for each L2_HR_Raster pixel.

aggregate_px_latlon	Aggregates the geodetic latitude/longitude coordinates for each L2_HR_Raster pixel. Note that this is only called when requesting a UTM raster product.
aggregate_wse_corrections	Aggregates the height correction from KaRIn crossovers, geoid height, solid earth tide height, geocentric load tide height (FES), geocentric load tide height (GOT), geocentric pole tide height, dry troposphere vertical correction, wet troposphere vertical correction, and ionosphere vertical correction for each L2_HR_Raster pixel.
aggregate_height	Aggregates the water surface height and water surface height uncertainty for each L2_HR_Raster pixel.
apply_wse_corrections	Applies corrections to the L2_HR_Raster aggregated height above reference ellipsoid to convert to geoid-relative WSE.
aggregate_wse_qual	Generates the WSE quality flags and the number of L2_HR_PIXC samples contributing to WSE for each L2_HR_Raster pixel.
aggregate_layover_impact	Aggregates the layover impact for each L2_HR_Raster pixel.
aggregate_water_area	Aggregates the water area, water area uncertainty, water fraction and water fraction uncertainty for each L2_HR_Raster pixel.
aggregate_water_area_qual	Generates the water area and water fraction quality flags and the number of L2_HR_PIXC samples contributing to water area and water fraction for each L2_HR_Raster pixel.
aggregate_dark_frac	Aggregates the dark water fraction for each L2_HR_Raster pixel.
aggregate_sig0_corrections	Aggregates the atmospheric model sigma0 correction for each L2_HR_Raster pixel
aggregate_sig0	Aggregates the sigma0 for each L2_HR_Raster pixel.
aggregate_sig0_qual	Generates the sigma0 quality flags and the number of L2_HR_PIXC samples contributing to sig0 for each L2_HR_Raster pixel.
aggregate_ice_flag	Aggregates the ice flags for each L2_HR_Raster pixel.
flag_missing_karin_data	Flags pixels where KaRIn data is missing.
flag_inner_swath	Flags inner swath pixels where data is expected to be missing.

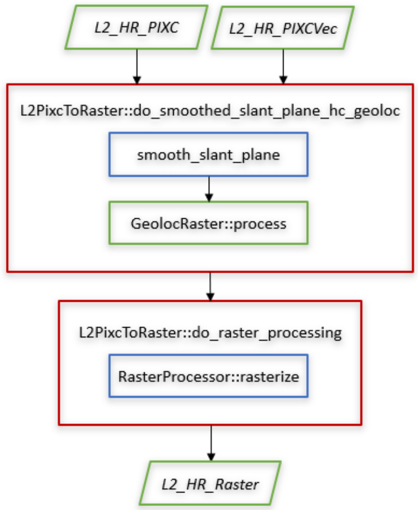

Figure 1. Flow diagram of the high-level Level 2 processing steps (functions) used to generate the L2_HR_Raster product.

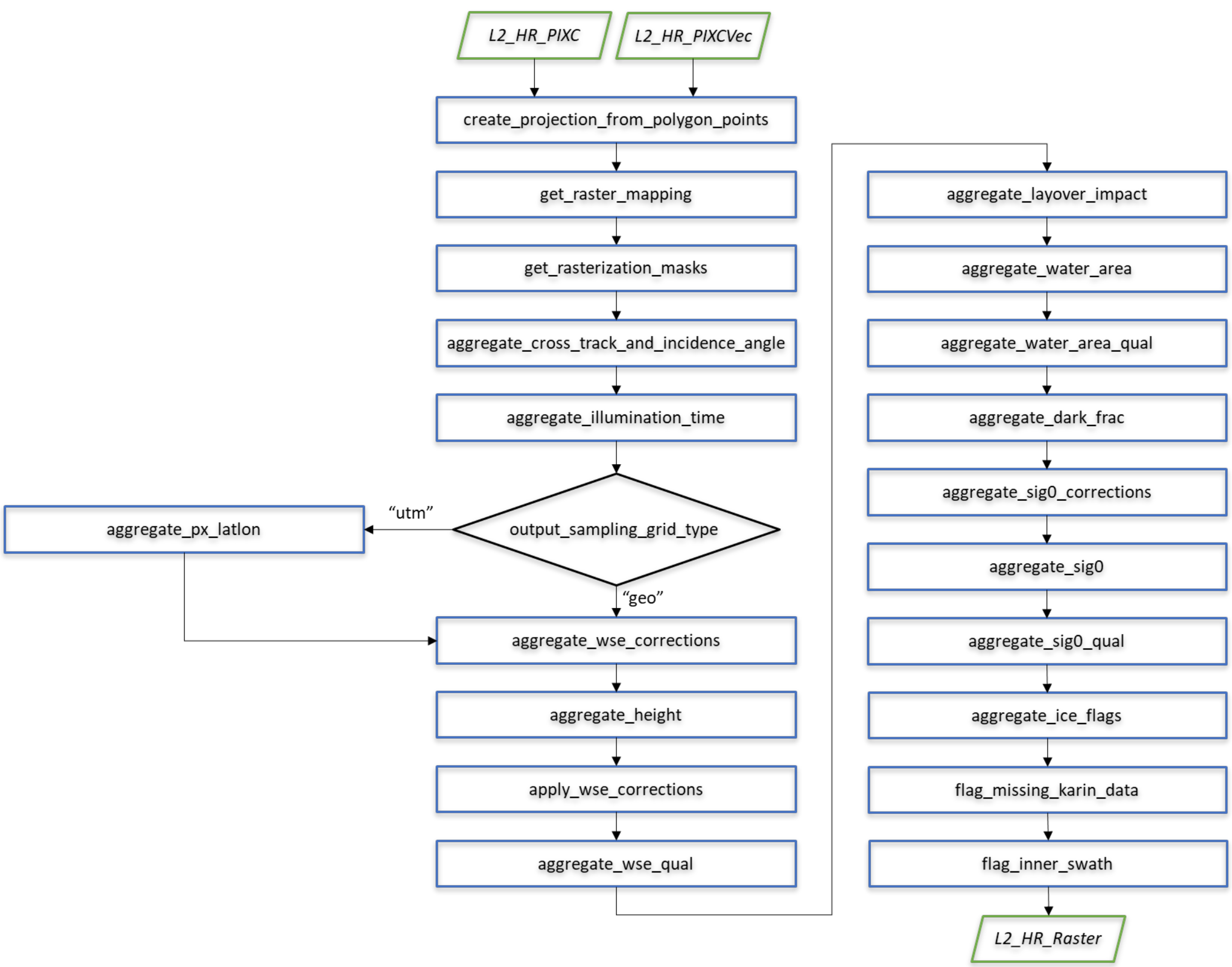

Figure 2. Flow diagram of the Level 2 rasterization processing steps (functions) used to

generate the L2_HR_Raster_product.

3 Algorithm Descriptions

3.1 do_smoothed_slant_plane_hc_geoloc

3.1.1 Purpose

The SWOT L2_HR_PIXC product provides an array of geolocated samples identified as water including latitude, longitude, and height information. Because of the SWOT viewing geometry, however, small height errors in the pixel 3-D locations can couple to large cross-track (horizontal) errors that may make L2_HR_PIXC sample-level information difficult to use. To reduce geolocation error, L2_HR_Raster processing includes an algorithm to adjust the noisy L2_HR_PIXC geolocation of each sample using smoothed height information. This processing step is called “height-constrained geolocation”. The results of the new geolocation are used to assign L2_HR_PIXC samples to L2_HR_Raster pixels. Note that the L2_HR_Raster processing does not use geolocations already estimated via height-constrained geolocation in L2_HR_River and L2_HR_Lake processing (available in L2_HR_PIXCVec) in order to maintain independence from the prior river and lake databases and any assumptions made in those respective processors. This allows the L2_HR_Raster product to be meaningful when the prior river and lake databases are unreliable, such as in the cases of flood events of water features that are not well captured by the prior databases.

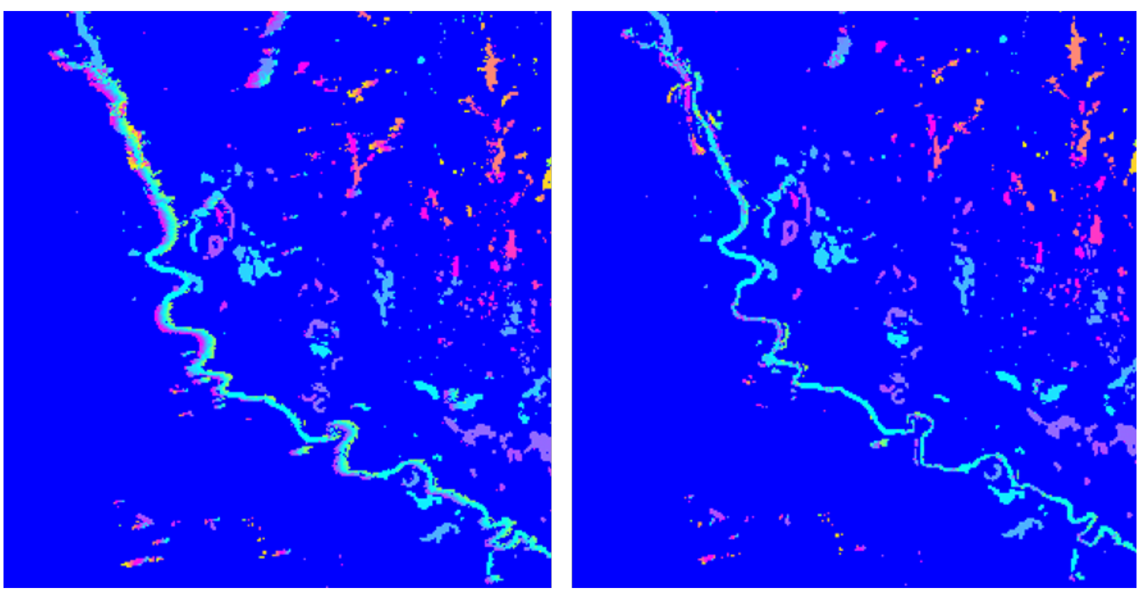

Figure 3. Example 100m L2_HR_Raster image without height-constrained geolocation (Left) and with height-constrained geolocation (Right).

The main idea underlying the height-constrained geolocation algorithm is to replace the phase in the interferometric height reconstruction system (which uses the Doppler, slant range, and interferometric phase to geolocate a given pixel in the radar scene) with a processed and smoothed height. Thus, the noisy interferometric phase (from the L2_HR_PIXC product) is replaced by a processed height computed using a fit to the pixel-level height values. By translating the pixels along the iso-range/Doppler contour from the position associated with the original, noisy, interferometric height to that associated with the smoothed, processed height, the horizontal geolocation of each sample is greatly improved. See the LakeSP ATBD for a more detailed algorithmic description of the height-constrained geolocation [4].

The L2_HR_PIXC heights are smoothed using quality and classification information in a series of three sequential median filters, which successively include more samples from the scene in order of decreasing confidence in the measurement. The smoothed heights of samples computed in earlier stages are not updated in later stages, but they do influence the smoothing of pixels that are included in the later stages, thereby prioritizing the best available water heights wherever possible. The first stage median filter operates only on good and suspect quality samples with classification information indicating good height accuracy (e.g. open water and water edges). The second stage median filter operates on the output of the first-stage filter after also incorporating samples with classification information indicating potentially lower height accuracy (e.g. land near water, dark water, and low-coherence water). The final stage then includes all samples not included in the first two stages to ensure that every L2_HR_PIXC sample is assigned a smoothed height.

Because of the steep SWOT imaging geometry, a small error in height can introduce a large error in cross-track geolocation. The cross-track error is largest at low incidence angles at the near-range side of the swath, where it can be hundreds of meters. After a great deal of averaging, the height error can be reduced to centimeter scales and the cross-track geolocation error reduced to meter scales. This function smooths the heights for both interferogram flattening and height-constrained geolocation and uses the smoothed heights to perform height-constrained geolocation.

3.1.2 Input Data

Description	Source
Level 2 KaRIn high rate water mask pixel cloud product	L2_HR_PIXC
Raster bounding polygon	L2_HR_Raster SAS
Raster run-time configuration parameters defining output sampling grid (UTM or geodetic latitude/longitude) and resolution.	L2_HR_Raster Run-time Configuration
Raster algorithmic configuration parameters defining aggregation methods, padding, the height-constrained geolocation smoothing median filter shape, quality flag masks, and classification values.	Param_L2_HR_Raster

3.1.3 Output Data

Description
Latitude, longitude and height for each L2_HR_PIXC sample after performing height constrained geolocation

3.1.4 Mathematical Statement

The L2_HR_Raster processor performs height-constrained geolocation of all input L2_HR_PIXC samples using smoothed height information to define the target heights for each sample, under the assumption of relative height uniformity within a local area. The smoothing algorithm is configured by input parameters to the algorithm.

Details regarding the height constrained geolocation algorithm are common to the L2_HR_Raster, L2_HR_RiverSP and L2_HR_LakeSP processors and are discussed in the referenced CNES technical note [5].

3.1.5 Accuracy

See the LakeSP ATBD [4] for a description of the height-constrained geolocation accuracy. Note that the height-constrained geolocations are computed by assuming a relatively smooth height for water within a local area.

3.2 do_raster_processing

3.2.1 Purpose

This function generates a raster image from input L2_HR_PIXC and L2_HR_PIXCVec data products.

3.2.2 Input Data

Description	Source
Level 2 KaRIn high rate water mask pixel cloud product	L2_HR_PIXC
Level 2 KaRIn high rate pixel vector attribute product	L2_HR_PIXCVec
Raster bounding polygon	L2_HR_Raster SAS
Raster run-time configuration parameters defining output sampling grid (UTM or geodetic latitude/longitude) and resolution.	L2_HR_Raster Run-time Configuration
Raster algorithmic configuration parameters defining aggregation methods, padding, the height-constrained geolocation smoothing median filter shape, quality flag masks, and classification values.	Param_L2_HR_Raster

3.2.3 Output Data

Description
Level 2 KaRIn high rate raster product

3.2.4 Mathematical Statement

See Sections 3.3 through 3.22 for mathematical descriptions of the individual rasterization methods.

3.2.5 Accuracy

See Sections 3.3 through 3.22 for information regarding the accuracy of the individual rasterization methods.

3.3 create_projection_from_polygon_points

3.3.1 Purpose

This function generates the output projection information from a polygon defining the extent of the L2_HR_Raster scene and the run-time configuration parameters. The projection information includes the output coordinate reference system, the minimum and maximum coordinate values, and the raster dimensions.

3.3.2 Input Data

Description	Source
Raster bounding polygon	L2_HR_Raster SAS
Raster run-time configuration parameters defining output sampling grid (UTM or geodetic latitude/longitude) and resolution	L2_HR_Raster Run-time Configuration

3.3.3 Output Data

Description
Raster coordinate reference system
Minimum and Maximum coordinate values and raster dimensions

3.3.4 Mathematical Statement

The L2_HR_raster projection is defined by the run-time configuration parameters and the bounding polygon.

If the output projection type is commanded to be UTM, the UTM zone is selected as the zone at the center of the bounding polygon, adjusted by +/- 1 zone as commanded by the run-time configuration. The Military Grid Reference System (MGRS) band is selected as the band at the center of the bounding polygon, adjusted by +/- 1 band as commanded by the run-time configuration. The pixel centers for data generated on a UTM grid are aligned with the central meridian of the UTM zone and the equator. The UTM easting coordinate at the central meridian of each zone is set at 500,000 meters, decreasing westward and increasing eastward. For MGRS bands in the southern hemisphere, the UTM northing coordinate at the equator is set at 10,000,000 meters, decreasing southward. For MGRS bands in the northern hemisphere, the UTM northing coordinate at the equator is set at 0 meters, increasing northward.

If the output projection type is commanded to be geodetic latitude/longitude, the pixel centers or data are aligned with the prime (Greenwich) meridian and the equator.

3.3.5 Accuracy

For L2_HR_Raster products produced on UTM grids, the UTM zone and MGRS band pair is selected based on the centroid of the input bounding polygon. This polygon is defined using the reference orbit nadir track with 125 m spacing and a local spherical approximation to determine the swath edges. As it is based on the reference orbit and not the as-flown orbit, the bounding polygon is identical for the equivalent tiles regardless of cycle.

3.4 get_raster_mapping

3.4.1 Purpose

This function maps L2_HR_PIXC samples onto the specified L2_HR_Raster sampling grid. Each L2_HR_Raster sample may incorporate information from many L2_HR_PIXC samples.

3.4.2 Input Data

Description	Source
Level 2 KaRIn high rate water mask pixel cloud product	L2_HR_PIXC
Raster coordinate reference system	L2_HR_Raster SAS

3.4.3 Output Data

Description
PIXC to Raster mapping

3.4.4 Mathematical Statement

The L2_HR_Raster processor maps L2_HR_PIXC samples onto the L2_HR_Raster sampling grid by first transforming each input sample into the designated output coordinate reference system, and subsequently calculating the indices of the output L2_HR_Raster pixel to which each L2_HR_PIXC sample should be aggregated. As the L2_HR_Raster pixel coordinates correspond to the center of the pixel, the indices are calculated as follows, where *i* and *j* are the L2_HR_Raster pixel indices, and *x* and *y* are the L2_HR_PIXC sample locations in the output coordinate reference system:

$$i = round((x - x_{min})/resolution) \tag{1}$$

$$j = round((y - y_{min})/resolution) \tag{2}$$

3.4.5 Accuracy

The accuracy of the mapping of L2_HR_PIXC samples to L2_HR_Raster pixels is dependent on the accuracy of the L2_HR_PIXC sample geolocations and the raster improved geolocations. As L2_HR_PIXC samples are assigned only to a single L2_HR_Raster pixel, water bodies may be spatially disconnected where the L2_HR_PIXC sampling is not much finer than the L2_HR_Raster sampling in cross track (e.g., at near range); no effort is made to ensure that connected water features in the L2_HR_PIXC input are connected in the L2_HR_Raster output.

3.5 get_rasterization_masks

3.5.1 Purpose

This function generates masks indicating which L2_HR_PIXC samples to aggregate for each L2_HR_Raster pixel. This function is called three times, to create different rasterization masks for WSE, water area, and sigma0. A fourth all-inclusive rasterization mask for miscellaneous data fields is then generated based on the three primary rasterization masks.

3.5.2 Input Data

Description	Source
Valid classes mask	L2_HR_Raster SAS
Input summary quality flags	L2_HR_Raster SAS
Raster coordinate reference system	L2_HR_Raster SAS

3.5.3 Output Data

Description
Mask of L2_HR_PIXC samples to aggregate
Mask of L2_HR_Raster pixels for which to aggregate data

3.5.4 Mathematical Statement

Samples included in the L2_HR_PIXC product each have a classification value describing the nature of the sample, including *open_water*, *land_near_water*, *water_near_land*, *dark_water*, etc. (see [6] for a more detailed description of all water classes). The input valid classes differ for each of the three primary rasterization masks; only interior (open) water, water edge, and dark water classes are valid for WSE and sigma0, while interior (open) water, water edge, dark water, and land edge classes are valid for water area. Only samples characterized as one of the valid classes are added to each rasterization mask.

Additionally, the L2_HR_PIXC product includes three main bitwise quality flags, indicating geolocation quality, classification quality, and sigma0 quality. The L2_HR_Raster SAS produces summary quality flags corresponding to each of these bitwise quality flags, using the algorithmic configuration parameters to categorize the bitwise flag states into “Good”, “Suspect”, “Degraded” and “Bad”, in order of decreasing quality. The summary quality flags used in get_rasterization_masks differ for each of the three primary rasterization masks; the geolocation qual and classification qual flags are used for the WSE and water area masks, while the geolocation qual, classification qual and sigma0 qual flags are used for the sigma0 mask. The combined summary quality for each L2_HR_PIXC sample is the worst quality value of the input summary quality flags. The get_rasterization_masks function first calculates the number of “Good” or “Suspect” L2_HR_PIXC samples per raster bin. If this number is greater than or equal to a threshold defined in the static algorithmic configuration parameters, only those samples are added to the rasterization mask. If this number is less than the algorithmic configuration parameter threshold, any available “Good”, “Suspect” or “Degraded” L2_HR_PIXC samples are added to the rasterization mask.

3.5.5 Accuracy

The accuracy of the rasterization masks is dependent on the accuracy of the L2_HR_PIXC quality flags as well as the underlying geolocation information. Additionally, the accuracy of all raster aggregation algorithms is dependent on whether or not “Degraded” samples are included for any given L2_HR_Raster pixel. See Sections 3.12, 3.15 and 3.19 for details about how this information is recorded in the L2_HR_Raster quality flags.

3.6 aggregate_cross_track_and_incidence_angle

3.6.1 Purpose

This function aggregates the L2_HR_PIXC approximate cross-track location and incidence angle for each L2_HR_Raster pixel.

3.6.2 Input Data

Description	Source
Approximate cross-track location	L2_HR_PIXC
Incidence angle	L2_HR_PIXC
Miscellaneous data rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.6.3 Output Data

Description
Aggregated approximate cross-track location
Aggregated incidence angle
Number of L2_HR_PIXC samples contributing to miscellaneous fields

3.6.4 Mathematical Statement

The approximate cross-track location and incidence angle for each L2_HR_Raster pixel are both calculated by a simple mean of the L2_HR_PIXC values as follows

$$cross\_track = \frac{\sum_{i=1}^{n} cross\_track_{i,pixc}}{n} \tag{3}$$

$$incidence\_angle = \frac{\sum_{i=1}^{n} incidence\_angle_{i,pixc}}{n} \tag{4}$$

Note that the approximate cross-track locations reported in the L2_HR_Raster product are the aggregated approximate cross-track locations from the contributing L2_HR_PIXC samples, rather than the approximate cross-track locations at the centroid of the L2_HR_Raster pixel. Likewise, the reported incidence angles are the aggregated incidence angles from the contributing L2_HR_PIXC samples, rather than the incidence angle at the centroid of the L2_HR_Raster pixel. Therefore, the cross-track locations reported in the product may not be evenly spaced even though the Raster grid is uniform.

Different aggregation methods are used for various fields in the product (e.g. inverse-variance weighting for height-related fields, composite sum for water area, simple mean for sigma0). For simplicity, and to provide approximate values of cross-track and incidence angle that are relevant for all fields, rather than only for height-related fields, a simple mean was chosen. The results should not depend significantly on the weighting for either of these fields.

3.6.5 Accuracy

The accuracy of the approximate cross-track locations is dependent upon the accuracy of the L2_HR_PIXC approximate cross-track locations. The accuracy of the incidence angle is dependent upon the accuracy of the L2_HR_PIXC incidence angle.

As the approximate cross track locations and incidence angle are aggregated as simple means per L2_HR_Raster pixel, they do not correspond to any exact cross-track locations and incidence angles from the contributing L2_HR_PIXC samples, nor do they correspond to the cross-track locations and incidence angles at the exact center of the L2_HR_Raster pixel.

3.7 aggregate_illumination_time

3.7.1 Purpose

This function aggregates the L2_HR_PIXC times of illumination of each sample (UTC and TAI) for each L2_HR_Raster pixel.

3.7.2 Input Data

Description	Source
Time of illumination of each sample (UTC)	L2_HR_PIXC
Time of illumination of each sample (TAI)	L2_HR_PIXC
Miscellaneous data rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.7.3 Output Data

Description
Aggregated time of illumination of each pixel (UTC)
Aggregated time of illumination of each pixel (TAI)

3.7.4 Mathematical Statement

The times of illumination (UTC and TAI) for each L2_HR_Raster pixel are calculated by a simple mean of the contributing L2_HR_PIXC time of illumination as follows:

$$illumination\_time\_utc = \frac{\sum_{i=1}^{n} illumination\_time\_utc_{i,pixc}}{n} \quad (5)$$

$$illumination\_time\_tai = \frac{\sum_{i=1}^{n} illumination\_time\_tai_{i,pixc}}{n} \tag{6}$$

3.7.5 Accuracy

The accuracy of the times of illumination is dependent upon the accuracy of the L2_HR_PIXC times of illumination. As the times of illumination are aggregated as a simple mean per L2_HR_Raster pixel, they do not correspond to any exact time of illumination from the contributing L2_HR_PIXC samples.

3.8 aggregate_px_latlon

3.8.1 Purpose

This function aggregates the latitude and longitude coordinates for each L2_HR_Raster pixel. Note that this function is only called when generating an L2_HR_Raster in a UTM projection as latitude and longitude coordinates are provided as 1-D vectors for L2_HR_Raster products on geodetic latitude/longitude grids.

3.8.2 Input Data

Description	Source
UTM easting coordinate mesh	L2_HR_Raster SAS
UTM northing coordinate mesh	L2_HR_Raster SAS
Miscellaneous data rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.8.3 Output Data

Description
Aggregated pixel latitude
Aggregated pixel longitude

3.8.4 Mathematical Statement

The latitude and longitude coordinate aggregation transforms the UTM easting and northing coordinates of the center of each L2_HR_Raster pixel to geodetic latitude and longitude.

3.8.5 Accuracy

As the latitude and longitude coordinates in L2_HR_Raster products on UTM grids are the coordinates of the center of the observed L2_HR_Raster pixel, the accuracy is only dependent on the coordinate conversion from UTM to geodetic latitude and longitude.

3.9 aggregate_wse_corrections

3.9.1 Purpose

This function aggregates the height corrections from each of the following terms for each L2_HR_Raster pixel: KaRIn crossovers, geoid height, solid earth tide height, geocentric load tide height (FES), geocentric load tide height (GOT), geocentric pole tide height, dry troposphere vertical correction, wet troposphere vertical correction, and ionosphere vertical correction.

3.9.2 Input Data

Description	Source
Height correction from KaRIn crossovers	L2_HR_PIXC
Geoid height	L2_HR_PIXC
Solid earth tide height	L2_HR_PIXC
Geocentric load tide height (FES)	L2_HR_PIXC
Geocentric load tide height (GOT)	L2_HR_PIXC
Geocentric pole tide height	L2_HR_PIXC
Dry troposphere vertical correction	L2_HR_PIXC
Wet troposphere vertical correction	L2_HR_PIXC
Ionosphere vertical correction	L2_HR_PIXC
Sensitivity of height estimate to interferogram phase	L2_HR_PIXC
Phase noise standard deviation	L2_HR_PIXC
WSE rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.9.3 Output Data

Description
Aggregated height correction from KaRIn crossovers
Aggregated geoid height
Aggregated solid earth tide height
Aggregated geocentric load tide height (FES)
Aggregated geocentric load tide height (GOT)
Aggregated geocentric pole tide height
Aggregated dry troposphere vertical correction
Aggregated wet troposphere vertical correction
Aggregated ionosphere vertical correction

3.9.4 Mathematical Statement

The WSE correction terms are calculated by an inverse variance weighted average using the height variance of each L2_HR_PIXC sample. Only L2_HR_PIXC samples corresponding to interior water (including dark water samples identified in L2_HR_PIXC processing through use of a prior water probability map) and water edges are used for the aggregated WSE correction calculations, as defined by the WSE aggregation mask. The height variance is calculated from the phase noise standard deviation and the sensitivity of height to phase reported in the L2_HR_PIXC product for each sample

$$\sigma_{height}^2 = \left(\sigma_{phase\ noise} * \frac{\partial height}{\partial phase}\right)^2 \tag{7}$$

The weighted average of each WSE correction term is then calculated

$$wse\_corr = \frac{\sum_{i=1}^{n} 1/\sigma_{i,height}^2 * wse\_corr_{i,pixc}}{\sum_{i=1}^{n} 1/\sigma_{i,height}^2} \tag{8}$$

3.9.5 Accuracy

The accuracy of the WSE corrections is dependent upon the accuracy of the L2_HR_PIXC WSE correction measurements and the estimated height variance. See [6] for detailed information regarding the interpolation of the WSE corrections to L2_HR_PIXC samples.

3.10 aggregate_height

3.10.1 Purpose

This function aggregates the L2_HR_PIXC height above reference ellipsoid for each L2_HR_Raster pixel and calculates the corresponding 1-sigma height uncertainty.

3.10.2 Input Data

Description	Source
Height above reference ellipsoid	L2_HR_PIXC
Effective number of rare looks	L2_HR_PIXC
Effective number of medium looks	L2_HR_PIXC
Power for plus_y channel	L2_HR_PIXC
Power for minus_y channel	L2_HR_PIXC
Sensitivity of height estimate to interferogram phase	L2_HR_PIXC
Sensitivity of the latitude estimate to interferogram phase	L2_HR_PIXC
Sensitivity of the longitude estimate to interferogram phase	L2_HR_PIXC
Phase noise standard deviation	L2_HR_PIXC
Flattened interferogram	L2_HR_Raster SAS
WSE rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.10.3 Output Data

Description
Aggregated height above reference ellipsoid
Aggregated height uncertainty

3.10.4 Mathematical Statement

The aggregated height is calculated by an inverse variance weighted average using the height variance of each L2_HR_PIXC sample. Only L2_HR_PIXC samples corresponding to interior water (including dark water samples identified in L2_HR_PIXC processing through use of a prior water probability map) and water edges are used for the aggregated height calculation, as defined by the WSE aggregation mask. The height variance is calculated from the phase noise standard deviation and the sensitivity of height to phase reported in the L2_HR_PIXC product for each sample

$$\sigma_{height}^2 = \left(\sigma_{phase\ noise} * \frac{\partial height}{\partial phase}\right)^2 \tag{9}$$

The weighted average of the L2_HR_PIXC sample heights is then calculated

$$height = \frac{\sum_{i=1}^{n} 1/\sigma_{i,height}^2 * height_{i,pixc}}{\sum_{i=1}^{n} 1/\sigma_{i,height}^2} \tag{10}$$

For a detailed mathematical description of the 1-sigma height uncertainty computation, see [7]. Note that this height uncertainty is used directly as the WSE uncertainty.

3.10.5 Accuracy

The accuracy of the height above reference ellipsoid is dependent upon the accuracy of the L2_HR_PIXC height measurements and estimated height variance. See Section 3.11 for simulated performance statistics for geoid-relative WSE after application of corrections to the height above the reference ellipsoid.

3.11 apply_wse_corrections

3.11.1 Purpose

This function applies corrections to the L2_HR_Raster aggregated height above the reference ellipsoid to convert to geoid-relative WSE.

3.11.2 Input Data

Description	Source
Aggregated height above reference ellipsoid	L2_HR_Raster SAS
Aggregated geoid height	L2_HR_Raster SAS
Aggregated solid earth tide height	L2_HR_Raster SAS
Aggregated geocentric load tide height (FES)	L2_HR_Raster SAS
Aggregated geocentric pole tide height	L2_HR_Raster SAS

3.11.3 Output Data

Description

Aggregated WSE

3.11.4 Mathematical Statement

The geoid height, solid earth tide height, geocentric load tide height (FES), and geocentric pole tide height are applied directly to the output height above the reference ellipsoid to convert to geoid-relative WSE:

$$WSE = height - (geoid + solid\_earth\_tide + load\_tide\_FES + pole\_tide) \quad (11)$$

3.11.5 Accuracy

The accuracy of the geoid-relative WSE is dependent upon the accuracy of the L2_HR_PIXC height measurements and the correction terms.

Table 2 describes the simulated performance statistics of the 100 m and 250 m resolution L2_HR_Raster outputs for the representative dataset (see Appendix B for a description of the representative dataset used in simulations of L2_HR_Raster performance). The statistics provided are for the geoid-relative WSE after application of corrections to the height above the reference ellipsoid. These statistics do not account for L2_HR_Raster pixel quality information (see Sections 3.12 and 3.15) as many aspects of quality flagging were not meaningfully captured in the simulated dataset. The errors include contributions from the instrument hardware as well as upstream data processing, not just errors from L2_HR_Raster algorithms.

Table 2. Summary WSE statistics for the L2_HR_Raster simulated nominal pixel-level performance using L2_HR_PIXC simulated data from the representative dataset.

Metric	| 68%ile |	50%ile	Mean
100 m L2_HR_Raster WSE error (cm)	14.513	0.346	-2.492
250 m L2_HR_Raster WSE error (cm)	7.943	0.288	-0.374

Figure 4 and Figure 5 show scatter density plots of the L2_HR_Raster WSE error in meters vs. the approximate cross-track location in meters. Note that the WSE uncertainty approximates the 68^{th} percentile error, and that the 250 m resolution L2_HR_Raster WSE improves the WSE error performance.

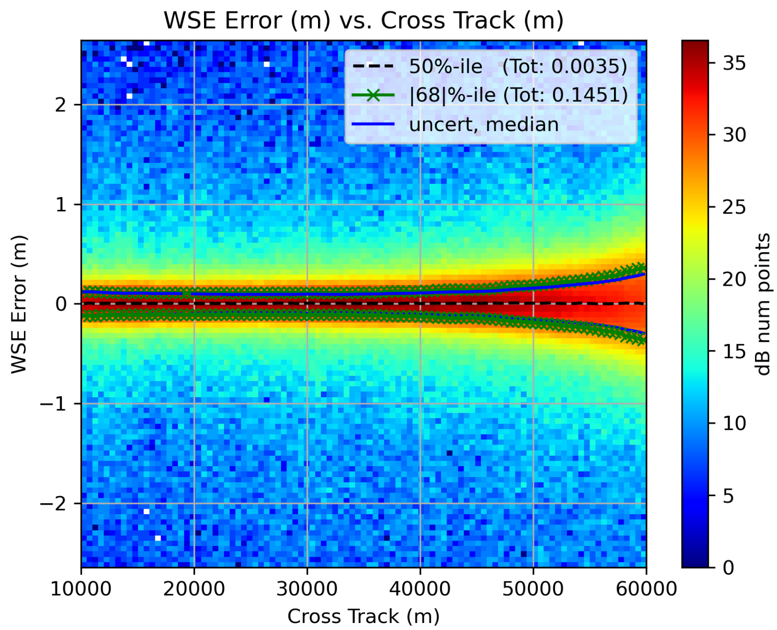

Figure 4. 100 m L2_HR_Raster WSE error as a function of approximate cross-track location.

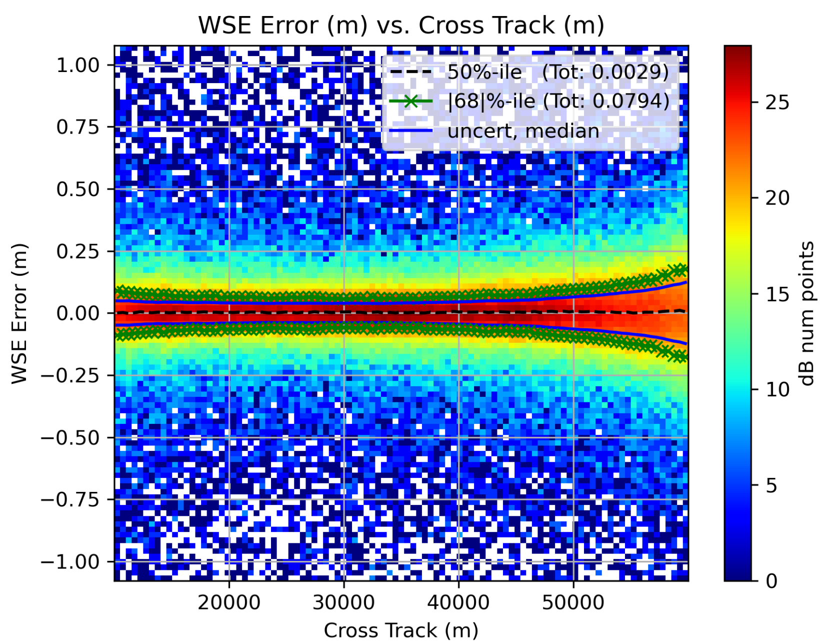

Figure 5. 250 m L2_HR_Raster WSE error as a function of approximate cross-track location.

3.12 aggregate_wse_qual

3.12.1 Purpose

This function generates the WSE quality flags for each L2_HR_Raster pixel.

3.12.2 Input Data

Description	Source
Aggregated WSE	L2_HR_Raster SAS
Aggregated WSE uncertainty	L2_HR_Raster SAS
Aggregated approximate cross-track location	L2_HR_Raster SAS
Classification quality flag	L2_HR_PIXC
Geolocation quality flag	L2_HR_PIXC
Bright land flag	L2_HR_PIXC
WSE rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.12.3 Output Data

Description
Aggregated WSE quality flag
Aggregated WSE bitwise quality flag
Number of L2_HR_PIXC pixels contributing to WSE

3.12.4 Mathematical Statement

The WSE bitwise quality flag includes a number of flag states indicating the quality of the L2_HR_Raster pixel WSE. Table 3 describes these flag states, along with the corresponding aggregated WSE quality flag state. Note that the aggregated WSE bitwise quality flag can represent multiple states at the same time, while the aggregated WSE quality flag state is set to the worst quality state for a given L2_HR_Raster pixel. This simple approach was chosen for conservatism given the lack of real SWOT data or appropriately representative simulations available when the algorithm was designed.

Table 3. Aggregated WSE bitwise quality flag state descriptions

Aggregated WSE bitwise quality flag state	Aggregated WSE quality flag state	Description
Classification quality suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to WSE had suspect classification quality, defined by the algorithmic configuration parameters.
Geolocation quality suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to WSE had suspect geolocation quality, defined by the algorithmic configuration parameters.
Large uncertainty suspect	Suspect	The aggregated WSE uncertainty is greater than a threshold defined in the algorithmic configuration parameters.
Bright land	Suspect	Any of the input L2_HR_PIXC samples contributing to WSE were flagged as bright land.
Few pixels	Suspect	The number of L2_HR_PIXC samples contributing to WSE is less than a threshold defined in the algorithmic configuration parameters.
Far range suspect	Suspect	The aggregated cross-track value is greater than a threshold defined in the algorithmic configuration parameters.
Near range suspect	Suspect	The aggregated cross-track value is less than a threshold defined in the algorithmic configuration parameters.

Classification quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to WSE had degraded classification quality, defined by the algorithmic configuration parameters.
Geolocation quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to WSE had degraded geolocation quality, defined by the algorithmic configuration parameters.
Value bad	Bad	The aggregated WSE is outside of a valid range defined in the algorithmic configuration parameters.
No pixels	Bad	No L2_HR_PIXC samples were aggregated to the L2_HR_Raster pixel for WSE.
Outside scene bounds	Bad	The L2_HR_Raster pixel is outside of the scene polygon, defined by a distance from the reference nadir track defined in the algorithmic configuration parameters. These L2_HR_Raster pixels are masked such that they will never contain valid data.
Inner swath	Bad*	The L2_HR_Raster pixel is less than a threshold distance away from the reference nadir track defined in the algorithmic configuration parameters. This value will only be set for L2_HR_Raster pixels with no data. See Section 3.22 for more information.
Missing KaRIn data	Bad*	The L2_HR_Raster pixel is in a region with missing KaRIn data. This flag is set if the input L2_HR_PIXC files do not cover the required along-track range of the L2_HR_Raster scene, or if there is a large KaRIn gap within the L2_HR_Raster scene. This value will only be set for L2_HR_Raster pixels with no data. See Section 3.21 for more information.

* Informational flags for L2_HR_Raster pixels with no data. These flag states are only set if there are no L2_HR_PIXC samples aggregated into the L2_HR_Raster bin. This means that while the aggregated WSE quality flag state will always be "Bad" for these pixels, these flag states do not explicitly set the aggregated WSE quality flag state to "Bad".

3.12.5 Accuracy

The accuracy of the WSE quality flagging is dependent upon the algorithmic configuration parameters defining valid thresholds.

3.13 aggregate_layover_impact

3.13.1 Purpose

This function aggregates the layover impact for each L2_HR_Raster pixel.

3.13.2 Input Data

Description	Source
Layover impact	L2_HR_PIXC
Sensitivity of height estimate to interferogram phase	L2_HR_PIXC
Phase noise standard deviation	L2_HR_PIXC
WSE rasterization mask	L2_HR_Raster SAS

PIXC to Raster mapping	L2_HR_Raster SAS

3.13.3 Output Data

Description
Aggregated layover impact

3.13.4 Mathematical Statement

The layover impact is calculated by an inverse variance weighted average using the height variance of each L2_HR_PIXC sample. Only L2_HR_PIXC samples corresponding to interior water (including dark water samples identified in L2_HR_PIXC processing through use of a prior water probability map) and water edges are used for the aggregated layover impact calculation, as defined by the WSE aggregation mask. The height variance is calculated from the phase noise standard deviation and the sensitivity of height to phase reported in the L2_HR_PIXC product for each sample:

$$\sigma^2_{height} = \left(\sigma_{phase\ noise} * \frac{\partial height}{\partial phase}\right)^2 \tag{12}$$

The layover impact is then calculated as

$$layover\_impact = \frac{\sum_{i=1}^{n} 1/\sigma^2_{i,height} * layover\_impact_{i,pixc}}{\sum_{i=1}^{n} 1/\sigma^2_{i,height}} \tag{13}$$

See [6] for a detailed description for the L2_HR_PIXC layover flagging method.

3.13.5 Accuracy

The accuracy of the layover impact is dependent upon the accuracy of the L2_HR_PIXC layover impact estimates and estimated height variance.

3.14 aggregate_water_area

3.14.1 Purpose

This function aggregates the L2_HR_PIXC water fraction and water area for each L2_HR_Raster pixel and calculates the corresponding 1-sigma uncertainties.

3.14.2 Input Data

Description	Source
Pixel area	L2_HR_PIXC
Water fraction	L2_HR_PIXC

Water fraction uncertainty	L2_HR_PIXC
Sensitivity of pixel area to reference height	L2_HR_PIXC
False detection rate	L2_HR_PIXC
Missed detection rate	L2_HR_PIXC
Classification	L2_HR_PIXC
Aggregated pixel latitude	L2_HR_Raster SAS
Water area rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.14.3 Output Data

Description
Aggregated water area
Aggregated water area uncertainty
Aggregated water fraction
Aggregated water fraction uncertainty

3.14.4 Mathematical Statement

The L2_HR_Raster water fraction and water area are calculated by a composite approach using the L2_HR_PIXC water fraction and pixel area. Samples included in the L2_HR_PIXC product each have a classification value describing the nature of the sample, including *open_water, land_near_water, water_near_land, dark_water,* etc. (see [6] for a more detailed description of all water classes). Interior (open) water and dark water samples are treated as being 100% water, while the L2_HR_PIXC water fraction is used as an estimate of water fraction for edge samples.

$$water\_area_{interior} = \sum_{i=1}^{n} \left\{ pixel\_area_{i,pixc} \,\middle|\, class_{\,i,pixc} \in \; interior\_classes \right\} \tag{14}$$

$$water\_area_{edge} = \sum_{i=1}^{n} \left\{ pixel\_area_{i,pixc} * water\_frac_{i,pixc} \,\middle|\, class_{\,i,pixc} \in \; edge\_classes \right\} \tag{15}$$

$$water\_area_{total} = water\_area_{interior} + water\_area_{edge} \tag{16}$$

For a detailed mathematical description of the 1-sigma water area uncertainty computation, see [7].

The water fraction and water fraction uncertainty estimates are calculated by dividing the aggregated water area and water area uncertainty estimates by the L2_HR_Raster pixel area in meters.

$$water\_fraction_{total} = \frac{water\_area_{total}}{pixel\_area} \tag{17}$$

$$water\_fraction\_uncert_{total} = \frac{water\_area\_uncert}{pixel\_area}$$

(18)

3.14.5 Accuracy

The accuracies of the water fraction and water area are dependent upon the accuracies of the L2_HR_PIXC water fraction and pixel area. The accuracy of the composite water area aggregation method is also dependent on the assumption that interior-water L2_HR_PIXC samples are 100% water, even if the L2_HR_PIXC water fraction is not 1.

Table 4 describes the simulated performance statistics of the 100 m and 250 m resolution L2_HR_Rasters for the representative dataset (see Appendix B for a description of the representative dataset used in simulations of L2_HR_Raster performance). These statistics do not account for L2_HR_Raster pixel quality information (see Sections 3.12 and 3.15) as many aspects of quality flagging were not meaningfully captured in the simulated dataset. The errors include contributions from the instrument hardware as well as upstream data processing, not just errors from L2_HR_Raster algorithms.

Table 4. Summary water area statistics for the L2_HR_Raster simulated nominal pixel-level performance using L2_HR_PIXC simulated data from the representative dataset.

Metric	| 68%ile |	50%ile	Mean
100 m L2_HR_Raster water area percent error	16.464	1.066	7.429
250 m L2_HR_Raster water area percent error	14.693	0.827	3.984

Figure 6 and Figure 7 show scatter density plots of the L2_HR_Raster water area percent error vs. the approximate cross-track location in meters.

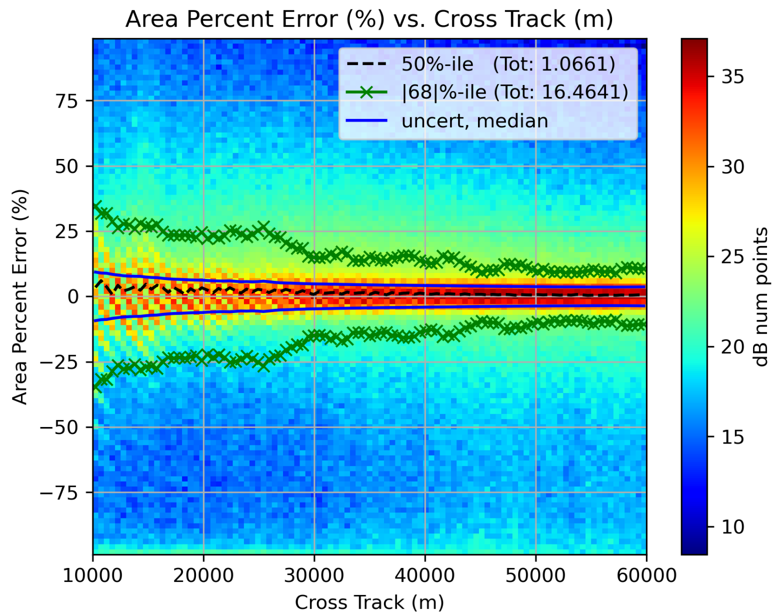

Figure 6. 100m L2_HR_Raster water area percent error as a function of approximate cross-track location

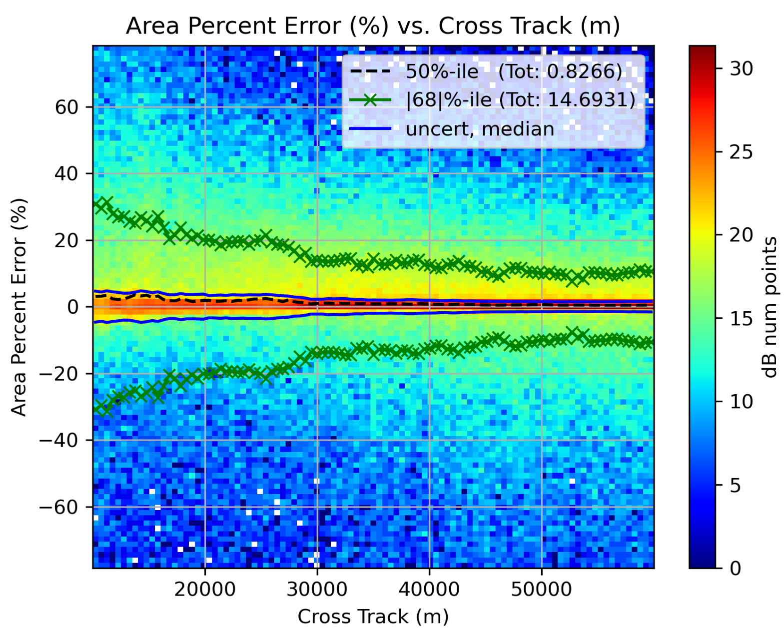

Figure 7. 250m L2_HR_Raster water area percent error as a function of approximate cross-track location

3.15 aggregate_water_area_qual

3.15.1 Purpose

This function generates the water area quality flags for each L2_HR_Raster pixel.

3.15.2 Input Data

Description	Source
Aggregated water fraction	L2_HR_Raster SAS
Aggregated water fraction uncertainty	L2_HR_Raster SAS
Aggregated approximate cross-track location	L2_HR_Raster SAS
Classification quality flag	L2_HR_PIXC
Geolocation quality flag	L2_HR_PIXC
Bright land flag	L2_HR_PIXC
Water fraction	L2_HR_PIXC
Water area rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.15.3 Output Data

Description
Aggregated water area quality flag
Aggregated water area bitwise quality flag
Number of L2_HR_PIXC samples contributing to water area

3.15.4 Mathematical Statement

The water area bitwise quality flag includes a number of flag states indicating the quality of the L2_HR_Raster pixel water area and water fraction. Table 5 describes these flag states, along with the corresponding aggregated water area quality flag state. Note that the aggregated water area bitwise quality flag can represent multiple states at the same time, while the aggregated water area quality flag state is set to the worst quality state for a given L2_HR_Raster pixel.

Table 5. Aggregated water area bitwise quality flag state descriptions

Aggregated water area bitwise quality flag state	Aggregated water area quality flag state	Description
Classification quality suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to water area had suspect classification quality, defined by the algorithmic configuration parameters.
Geolocation quality suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to water area had suspect geolocation quality, defined by the algorithmic configuration parameters.
Water fraction suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to water area had water fraction outside of a range based on a threshold defined in the algorithmic configuration parameters.
Large uncertainty suspect	Suspect	The aggregated water fraction uncertainty is greater than a threshold defined in the algorithmic configuration parameters.

Bright land	Suspect	Any of the input L2_HR_PIXC samples contributing to water area were flagged as bright land.
Few pixels	Suspect	The number of L2_HR_PIXC samples contributing to water area is less than a threshold defined in the algorithmic configuration parameters.
Far range suspect	Suspect	The aggregated cross-track value is greater than a threshold defined in the algorithmic configuration parameters.
Near range suspect	Suspect	The aggregated cross-track value is less than a threshold defined in the algorithmic configuration parameters.
Classification quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to water area had degraded classification quality, defined by the algorithmic configuration parameters.
Geolocation quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to water area had degraded geolocation quality, defined by the algorithmic configuration parameters.
Value bad	Bad	The aggregated water fraction is outside of a valid range defined in the algorithmic configuration parameters.
No pixels	Bad	No L2_HR_PIXC samples were aggregated to the L2_HR_Raster pixel for water area.
Outside scene bounds	Bad	The L2_HR_Raster pixel is outside of the scene polygon, defined by a distance from the reference nadir track defined in the algorithmic configuration parameters. These L2_HR_Raster pixels are masked such that they will never contain valid data.
Inner swath	Bad*	The L2_HR_Raster pixel is less than a threshold distance away from the reference nadir track defined in the algorithmic configuration parameters. This value will only be set for L2_HR_Raster pixels with no data. See Section 3.22 for more information.
Missing KaRIn data	Bad*	The L2_HR_Raster pixel is in a region with missing KaRIn data. This flag is set if the input L2_HR_PIXC files do not cover the required along-track range of the L2_HR_Raster scene, or if there is a large KaRIn gap within the L2_HR_Raster scene. This value will only be set for L2_HR_Raster pixels with no data. See Section 3.21 for more information.

* Informational flags for L2_HR_Raster pixels with no data. These flag states are only set if there are no L2_HR_PIXC samples aggregated into the L2_HR_Raster bin. This means that while the aggregated water area quality flag state will always be “Bad” for these pixels, these flag states do not explicitly set the aggregated water area quality flag state to “Bad”.

3.15.5 Accuracy

The accuracy of the water area quality flagging is dependent upon the algorithmic configuration parameters defining valid thresholds.

3.16 aggregate_dark_frac

3.16.1 Purpose

This function calculates the dark water fraction for each L2_HR_Raster pixel.

3.16.2 Input Data

Description	Source
Classification	L2_HR_PIXC
Pixel area	L2_HR_PIXC
Water fraction	L2_HR_PIXC
Water area rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.16.3 Output Data

Description
Aggregated dark water fraction

3.16.4 Mathematical Statement

The dark water area is calculated as the sum of L2_HR_PIXC pixel areas for all dark water samples contributing to a raster pixel. This assumes that dark water samples are 100% water.

$$water\_area_{dark} = \sum_{i=1}^{n} \left\{ water\_area_{i,pixc} \,\middle|\, class_{\,i,pixc} \in dark\_water\_classes \right\} \tag{19}$$

The dark water fraction is then determined by taking the ratio of the dark water area and the total water area for each L2_HR_Raster pixel, where the total water area is calculated using the method described in Section 3.14.

$$water\_fraction_{dark} = \frac{water\_area_{dark}}{water\_area_{total}} \tag{20}$$

3.16.5 Accuracy

The accuracy of the dark water fraction is dependent upon the accuracy of the water area and the L2_HR_PIXC dark water flagging algorithm.

3.17 aggregate_sig0_corrections

3.17.1 Purpose

This function aggregates the L2_HR_PIXC two-way atmospheric correction to sigma0 from model for each L2_HR_Raster pixel.

3.17.2 Input Data

Description	Source
Two-way atmospheric correction to sigma0 from model	L2_HR_PIXC
Sigma0 rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.17.3 Output Data

Description
Aggregated two-way atmospheric correction to sigma0 from model

3.17.4 Mathematical Statement

The two-way atmospheric correction to sigma0 from model values for each L2_HR_Raster pixel is calculated from a simple mean of the contributing L2_HR_PIXC two-way atmospheric corrections to the sigma0 from model values.

$$\sigma^0 corr = \frac{\sum_{i=1}^{n} \sigma^0 corr_{i,pixc}}{n} \tag{21}$$

3.17.5 Accuracy

The accuracy of the L2_HR_Raster two-way atmospheric correction to sigma0 from model values is dependent upon the accuracy of the L2_HR_PIXC two-way atmospheric correction to sigma0 from model values. See [6] for detailed information regarding the interpolation of this correction to L2_HR_PIXC samples.

3.18 aggregate_sig0

3.18.1 Purpose

This function aggregates the L2_HR_PIXC normalized radar cross section (NRCS) or sigma0 for each L2_HR_Raster pixel and calculates the corresponding 1-sigma sigma0 uncertainty.

3.18.2 Input Data

Description	Source
Sigma0	L2_HR_PIXC
Sigma0 uncertainty	L2_HR_PIXC
Sigma0 rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.18.3 Output Data

Description

Aggregated sigma0
Aggregated sigma0 uncertainty

3.18.4 Mathematical Statement

The sigma0 value for each L2_HR_Raster pixel is calculated by a simple mean of the contributing L2_HR_PIXC sample sigma0 measurements (as linear values, not values in decibels).

$$\sigma^0 = \frac{\sum_{i=1}^{n} \sigma_{i,pixc}^0}{n} \tag{22}$$

For a detailed mathematical description of the 1-sigma sigma0 uncertainty computation, see [7].

3.18.5 Accuracy

The accuracy of the L2_HR_Raster sigma0 values is dependent upon the accuracy of the L2_HR_PIXC sigma0 measurements.

3.19 aggregate_sig0_qual

3.19.1 Purpose

This function generates the sigma0 quality flags for each L2_HR_Raster pixel.

3.19.2 Input Data

Description	Source
Aggregated sigma0	L2_HR_Raster SAS
Aggregated sigma0 uncertainty	L2_HR_Raster SAS
Aggregated approximate cross-track location	L2_HR_Raster SAS
Sigma0 quality flag	L2_HR_PIXC
Classification quality flag	L2_HR_PIXC
Geolocation quality flag	L2_HR_PIXC
Bright land flag	L2_HR_PIXC
Sigma0 rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.19.3 Output Data

Description
Aggregated sigma0 quality flag
Aggregated sigma0 bitwise quality flag
Number of L2_HR_PIXC samples contributing to sigma0

3.19.4 Mathematical Statement

The sigma0 bitwise quality flag includes a number of flag states indicating the quality of the L2_HR_Raster pixel sigma0. Table 6 describes these flag states, along with the corresponding aggregated sigma0 quality flag state. Note that the aggregated sigma0 bitwise quality flag can represent multiple states at the same time, while the aggregated sigma0 quality flag state is set to the worst quality state for a given L2_HR_Raster pixel.

Table 6. Aggregated sigma0 bitwise quality flag state descriptions

Aggregated sigma0 bitwise quality flag state	Aggregated sigma0 quality flag state	Description
Sigma0 quality suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to sigma0 had suspect sigma0 quality, defined by the algorithmic configuration parameters.
Classification quality suspect	Suspect	Any of the input L2_HR_PIXC samples contributing to sigma0 had suspect classification quality, defined by the algorithmic configuration parameters.
Geolocation quality suspect	Suspect	Any of the input L2_HR_PIXC contributing to sigma0 had suspect geolocation quality, defined by the algorithmic configuration parameters.
Large uncertainty suspect	Suspect	The aggregated sigma0 uncertainty is greater than a threshold defined in the algorithmic configuration parameters.
Bright land	Suspect	Any of the input L2_HR_PIXC samples contributing to sigma0 were flagged as bright land.
Few pixels	Suspect	The number of L2_HR_PIXC samples contributing to sigma0 is less than a threshold defined in the algorithmic configuration parameters.
Far range suspect	Suspect	The aggregated cross-track value is greater than a threshold defined in the algorithmic configuration parameters.
Near range suspect	Suspect	The aggregated cross-track value is less than a threshold defined in the algorithmic configuration parameters.
Sigma0 quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to sigma0 had degraded sigma0 quality, defined by the algorithmic configuration parameters.
Classification quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to sigma0 had degraded classification quality, defined by the algorithmic configuration parameters.
Geolocation quality degraded	Degraded	Any of the input L2_HR_PIXC samples contributing to sigma0 had degraded geolocation quality, defined by the algorithmic configuration parameters.
Value bad	Bad	The aggregated water fraction is outside of a valid range defined in the algorithmic configuration parameters.
No pixels	Bad	No L2_HR_PIXC samples were aggregated to the L2_HR_Raster pixel for sigma0.
Outside scene bounds	Bad	The L2_HR_Raster pixel is outside of the scene polygon, defined by a distance from the reference nadir track defined in the algorithmic configuration parameters. These L2_HR_Raster pixels are masked such that they will never contain valid data.
Inner swath	Bad*	The L2_HR_Raster pixel is less than a threshold distance away from the reference nadir track defined in the

		algorithmic configuration parameters. This value will only be set for L2_HR_Raster pixels with no data. See Section 3.22 for more information.
Missing KaRIn data	Bad*	The L2_HR_Raster pixel is in a region with missing KaRIn data. This flag is set if the input L2_HR_PIXC files do not cover the required along-track range of the L2_HR_Raster scene, or if there is a large KaRIn gap within the L2_HR_Raster scene. This value will only be set for L2_HR_Raster pixels with no data. See Section 3.21 for more information.

* Informational flags for L2_HR_Raster pixels with no data. These flag states are only set if there are no L2_HR_PIXC samples aggregated into the L2_HR_Raster bin. This means that while the aggregated water area quality flag state will always be “Bad” for these pixels, these flag states do not explicitly set the aggregated water area quality flag state to “Bad”.

3.19.5 Accuracy

The accuracy of the water area quality flagging is dependent upon the algorithmic configuration parameters defining valid thresholds.

3.20 aggregate_ice_flag

3.20.1 Purpose

This function aggregates the ice flags for each L2_HR_Raster pixel. It is called twice in the rasterization process, once for the climatological ice flag, and once for the dynamic ice flag.

3.20.2 Input Data

Description	Source
Ice flag	L2_HR_PIXCVec
Miscellaneous data rasterization mask	L2_HR_Raster SAS
PIXC to Raster mapping	L2_HR_Raster SAS

3.20.3 Output Data

Description
Aggregated ice flag

3.20.4 Mathematical Statement

The ice flagging method is defined such that if the input ice flag is set to the same value for all input L2_HR_PIXC samples, the aggregated ice flag is set to that same value. Otherwise, the aggregated ice flag is set to the partial cover flag value.

3.20.5 Accuracy

The accuracy of the ice flagging is dependent upon the L2_HR_PIXCVec ice flags. See [8] for a detailed description of the L2_HR_PIXCVec ice flagging approach.

3.21 flag_missing_karin_data

3.21.1 Purpose

This function flags L2_HR_Raster pixels where KaRIn data is missing, updating the bitwise quality flags only for pixels where valid data does not already exist.

3.21.2 Input Data

Description	Source
Level 2 KaRIn high rate water mask pixel cloud product	L2_HR_PIXC
PIXC to Raster mapping	L2_HR_Raster SAS

3.21.3 Output Data

Description
Updated WSE bitwise quality flag
Updated water area bitwise quality flag
Updated sigma0 bitwise quality flag

3.21.4 Mathematical Statement

Missing KaRIn data is flagged by creating swath polygons covering azimuth lines of non-missing L2_HR_PIXC data. Lines where the L2_HR_PIXC line quality is flagged as “large_karin_gap” are excluded from these polygons. Similarly, spans of data in along-track are excluded from these polygons if the observation time [from the L2_HR_PIXC Time Varying Parameters (TVP)] between successive lines is greater than a threshold defined in the algorithmic configuration parameters. The polygon edge points are defined using a local spherical projection and the spacecraft location and velocity vector provided in the TVP, and the cross-track extent is chosen to be a value larger than the raster scene extent such that all cross-track pixels are masked. Note that the polygons indicate extant data in order to properly handle missing data from poor azimuth line coverage. The polygons are then converted to a binary mask, where any L2_HR_Raster pixels not touching a polygon are flagged as missing KaRIn data. This mask is used to add the “missing_karin_data” flag state to the WSE, water area and sigma0 bitwise quality flags.

3.21.5 Accuracy

The accuracy of the missing KaRIn data flagging algorithm is dependent upon the L2_HR_PIXC line quality flag and the algorithmic configuration parameter defining the valid time threshold. As it is defined by L2_HR_Raster pixels not touching an extant data polygon, the flag is conservative, only flagging L2_HR_Raster pixels where every corresponding azimuth line is missing.

3.22 flag_inner_swath

3.22.1 Purpose

This function flags inner swath L2_HR_Raster pixels where data is expected to be missing, updating the bitwise quality flags only for pixels where valid data does not already exist.

3.22.2 Input Data

Description	Source
Level 2 KaRIn high rate water mask pixel cloud product	L2_HR_PIXC
PIXC to Raster mapping	L2_HR_Raster SAS

3.22.3 Output Data

Description
Updated WSE bitwise quality flag
Updated water area bitwise quality flag
Updated sigma0 bitwise quality flag

3.22.4 Mathematical Statement

The inner swath is flagged by creating a swath polygon with a cross-track extent defined by an algorithmic configuration parameter. The polygon edge points are defined using a local spherical projection and the spacecraft location and velocity vector provided in the TVP, and an along-track buffer is added to flag inner swath pixels even if the TVP lines do not cover the entire L2_HR_Raster scene. The polygon is then converted to a binary mask, where any L2_HR_Raster pixels touching the polygon are flagged as inner swath pixels. This mask is used to add the “inner_swath” flag state to the WSE, water area and sigma0 bitwise quality flags.

3.22.5 Accuracy

The accuracy of the inner swath flagging algorithm is dependent upon the L2_HR_PIXC line quality flag and the algorithmic configuration parameter defining the distance threshold. As it is defined by L2_HR_Raster pixels touching the inner swath polygon, the flag is inclusive of pixels at the edge of the inner swath region. The accuracy of the inner swath flagging algorithm is diminished for regions of missing TVP line coverage, as the spacecraft location and velocity vectors do not exist. In these regions, valid L2_HR_Raster pixels are not expected, and the “missing_karin_data” flag should be set.

4 References

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Appendix A. **Acronyms**

AD	Applicable Document
ATBD	Algorithm Theoretical Basis Document
CNES	Centre National d'Études Spatiales
CRID	Composite Release Identifier
CRS	Coordinate Reference System
ECMWF	European Centre for Medium-Range Weather Forecasts
HR	High Rate
JPL	Jet Propulsion Laboratory
KaRIn	Ka-band Radar Interferometer
LR	Low Rate
MGRS	Military Grid Reference System
NASA	National Aeronautics and Space Administration
ODP	On-Demand Product
SDP	Standard Data Product
SDS	Science Data System
SWOT	Surface Water Ocean Topography
TAI	Temps Atomique International / International Atomic Time
TBC	To Be Confirmed
TBD	To Be Determined
TVP	Time Varying Parameters
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
WSE	Water Surface Elevation

Appendix B. **Simulations**

All simulated L2_HR_Raster outputs were created using ideal and nominal simulated L2_HR_PIXC products. See [6] for a description of the representative dataset simulation process up to the beginning of L2_HR_Raster processing.

The representative dataset contains a total of 47 unique simulated scenes covering 118 unique tiles observed by 74 SWOT passes, yielding 359 valid (i.e., containing data) scene-pass-tile combinations in total. As L2_HR_Raster scenes nominally rasterize 2x2 sets of tiles at a time, the number of L2_HR_Raster scenes in the representative dataset is lower, at 305 scenes. Simulated L2_HR_Raster pixels must be located between 10 km and 60 km cross-track in order to be included in the L2_HR_Raster performance statistics in this document. Additionally, only simulated L2_HR_Raster pixels with more than 20% water are included in the L2_HR_Raster performance statistics in order to exclude most water bodies smaller than the size of the L2_HR_Raster pixels. Note that useful data may still be reported for such pixels in the SWOT products, but the pixels are ignored when compiling the performance statistics. A summary of the filtering criteria is provided in Table 7.

Note that there are not explicit performance requirements levied upon L2_HR_Raster products. However, the 100 m and 250 m resolution L2_HR_Raster standard data products (SDPs) can be compared to the goals for $(100\text{ m})^2$ terrestrial surface water body WSE and water area errors and the requirements for $(250\text{ m})^2$ terrestrial surface water body WSE and water area errors [9].

Simulated SWOT performance estimates require both truth and nominal processed data. Raster "truth" data were generated by evenly distributing water observation pixels over truth water masks and assigning WSEs to each pixel from the truth heights (based on airborne lidar data) used as inputs to the simulation in order to form an artificial L2_HR_PIXC product. Directly mapping truth heights to pixel heights eliminates sources of error due to LR_HR_PIXC or L1_HR_SLC processing. These artificial L2_HR_PIXC products are then processed through L2_HR_Raster processing to create "truth" L2_HR_Raster products. The truth data may be spurious due to unrealistic height profiles resulting from artifacts in the height truth, inaccurate "truth" water masks, or discrepancies between the water elevation and extent. Moreover, unrealistic discrepancies between the truth data and the reference data due to temporal changes (e.g., river migration) are possible.

It is important to note that the "truth" L2_HR_Raster products are processed with different configuration parameters than the "nominal" tiles. As height uncertainty is not modeled for the truth products, a simple mean is used instead of the inverse variance weight for height and WSE related data fields. Furthermore, the truth water mask does not provide L2_HR_PIXC level partial water fraction; each truth water pixel is used as 100% water and therefore a simple sum is used instead of the composite aggregation method. Additionally, as the geolocations are ideal, height-constrained geolocation is not required for the truth data.

Table 7. Representative dataset filtering criteria for SWOT L2_HR_Raster statistical analysis

Filter type	Filtering criterion
Cross-track position	Between 10 km and 60 km
Water fraction	Greater than 0.2