Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Level 2 KaRIn high rate floodplain DEM product
Short Name: L2_HR_FPDEM

Revision A

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National Aeronautics and Space Administration
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California Institute of Technology

CHANGE LOG

VERSION	DATE	SECTIONS CHANGED	REASON FOR CHANGE
Initial Release	2021-12-15	All	Initial version
Revision A	2022-09-30	All	Updates following SME review

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1 Introduction

1.1 Purpose

The purpose of this Product Description Document is to describe the Level 2 Ka-band Radar Interferometer (KaRIn) high-rate (HR) floodplain digital elevation model (DEM) product from the Surface Water Ocean Topography (SWOT) mission. This data product is also referenced by the short name L2_HR_FPDEM.

1.2 Document Organization

Section 2 provides a general description of the product, including its purpose and latency.

Section 3 provides the structure of the product, including granule definition, file organization, spatial resolution, temporal and spatial organization of the content, the size and data volume.

Section 4 provides qualitative descriptions of the information provided in the product.

Section 5 provides a detailed identification of the individual fields within the L2_HR_FPDEM product, including for example their units, size, coordinates, etc.

Section 6 provides the references.

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

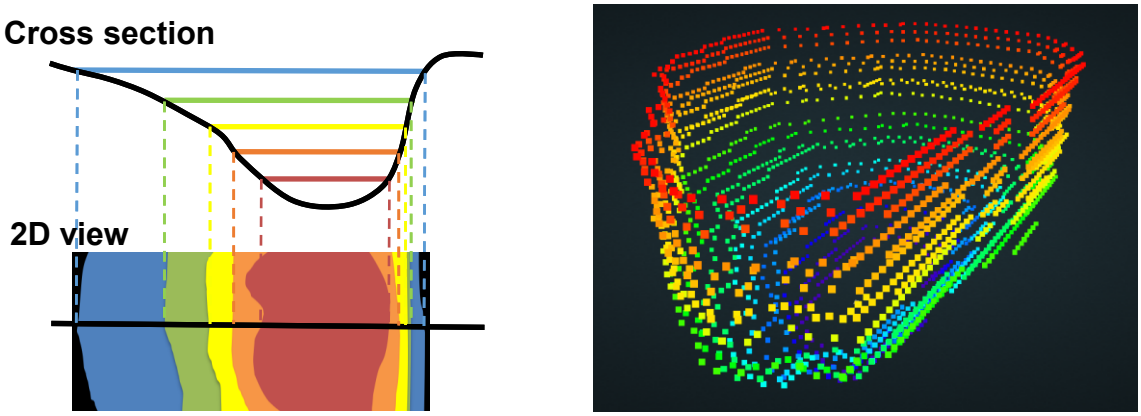
1.3 Document Conventions

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.

2 Product Description

2.1 Purpose

The L2_HR_FPDEM product contains floodplain surface elevations derived from SWOT HR data acquired over a period of at least 18 months. It is a DEM of land elevations near the boundary of water bodies (rivers, lakes, reservoirs, estuaries…), built with the so-called "bathtub ring" approach, using the smoothed geolocated heights [1] of the water surface boundaries of the different acquisition dates. These water/land boundaries are assumed to be representative of the bathymetry. We define a water/land boundary as the center of a pixel classified as water that has a neighbor pixel classified as land. As illustrated in Figure 1, for a small lake where the water can be considered to be flat, the edge pixels yield an iso-elevation curve each time the water body is observed. In the general case, slopes are also taken into account. Using the entire stack of geolocated edge pixels and associated elevations, we obtain after outlier removal and interpolation, a partial bathymetry between the minimum and maximum water stages observed in the period. Further details are provided in the Algorithm Theoretical Basis Document (ATBD) [2].



(a) (b)

Figure 1: Illustrations of floodplain DEM extraction based on the bathtub ring approach

The main L2_HR_FPDEM product is a global raster product, covering all detected water bodies present in the Level 2 high-rate pixel cloud (L2_HR_PIXC) [3] and pixel cloud vector attribute (L2_HR_PIXCVec) [4] products. It is fundamentally limited by the observed variations in extent and height. The longer the time series, and the larger the variations in water level, the more complete and accurate the estimated bathymetry will generally be. If the water elevation of a given water body does not vary in the observation period, its estimated bathymetry in principle reduces to a rasterized contour.

A point cloud version of the floodplain DEM, containing all edge pixels with their acquisition date, is provided in separate files, allowing expert users to derive tailor-made floodplain DEMs, for example covering a shorter time period in an area where the bathymetry changes rapidly.

The L2_HR_FPDEM product is useful for many scientific applications. The estimated bathymetry can be used to improve discharge and storage change estimations, to study flooding events, etc. As it only covers part of the floodplain or bathymetry, it will often be necessary to combine it with other DEMs.

2.2 Latency

The L2_HR_FPDEM product is only produced during reprocessing campaigns, starting with the one that takes place ~2 years after launch, based on ~18 months of SWOT HR data acquired over continental water surfaces from the 21-day repeat-pass science orbit. The final version of the L2_HR_FPDEM product will cover the entire science mission period (~3 years).

3 Product Structure

3.1 Granule Definition

The L2_HR_FPDEM product is divided into 1°×1° non-overlapping latitude/longitude tiles, similar to those of the SRTM/NASADEM global DEM [5].

The granules of the L2_HR_FPDEM product are thus not linked to the SWOT swath, as the product is obtained by combining information from many SWOT acquisitions, from both ascending and descending passes, as illustrated in Figure 2.

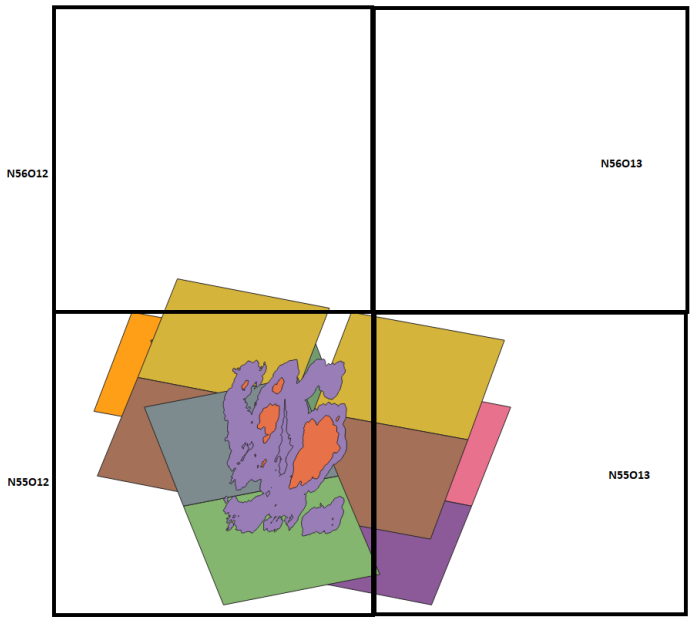


Figure 2: Illustration of the fixed 1°×1° raster grid of the floodplain DEM product, whose content is based on SWOT HR tile products from all passes intersecting the grid cell, over many orbit cycles (only some of the tiles are shown here, as rectangles of different colors).

3.2 File Organization

The L2_HR_FPDEM adopts the NetCDF-4 file format. Each FPDEM tile consists of a single NetCDF file containing rasterized floodplain DEM at the specified posting. Each file contains a set of global attributes and a number of variable layers. The time-tagged (lat, lon, elevation) point cloud from which the raster floodplain DEM is built, is included in a separate file, for expert users.

Table 1. Description of the files of the L2_HR_FPDEM product

File	Name	Description
1	Level 2 KaRIn high-rate gridded floodplain DEM	Provides rasterized estimated elevation over floodplain areas (partial bathymetry).
2	Level 2 KaRIn high-rate ungridded floodplain DEM	Provides the point cloud of water/land edge pixels from which the raster floodplain DEM is built.

3.3 File Naming Convention

The L2_HR_FPDEM products adopt the following file naming convention:

SWOT_L2_HR_FPDEM_<FileIdentifier>_<NorthingEastingTileCoordinates>_
<RangeBeginningDateTime>_<RangeEndingDateTime>_<CRID>_<ProductCounter>.nc

The <*FileIdentifier*> field indicates whether it is the floodplain DEM in Gridded (i.e. raster) format (main product), or the point cloud of water/land edge pixels prior to rasterization, here called Ungridded format (expert product).

The <*NorthingEastingTileCoordinates*> contains the Northing coordinates w.r.t. the equator, and the Easting coordinates w.r.t. the Greenwich meridian, using a nomenclature equivalent to that of SRTM/NASADEM as described in [5]. For example, with this naming convention, tile N056E012 covers 1° North and East from its Southwestern corner 56° North and 12° East.

The <*RangeBeginningDateTime*> and <*RangeEndingDateTime*> provide the time period of the SWOT data used to compute the global data product. The floodplain DEM product is a multi-temporal product that is based on at least a year of data, and ultimately all the data acquired during the 3-year science phase of the SWOT mission.

The <*CRID*> is the composite release identifier. It contains the version code of the data system used to generate the product, which changes if any processing software and/or auxiliary inputs are updated. The <*ProductCounter*> identifies the version of product that may have been generated multiple times with the same version of processing software.

Example filenames for a L2_HR_FPDEM product:

SWOT_L2_HR_FPDEM_Gridded_N45E28_20210512T072103_20230603T075103_PGA2_01.nc
SWOT_L2_HR_FPDEM_Ungridded_N45E28_20210512T072103_20230603T075103_PGA2_01.nc

3.4 Spatial Sampling and Resolution

In this document, the term “sampling” is usually equivalent to the terms “posting” or “ground sample distance” in other contexts. One individual data value is called a sample. Samples from a 2-D image array are often also called “pixels.” When the location of pixel is discussed in this document, the location refers to the center of the pixel (not a corner).

L2_HR_FPDEM raster data are stored as 2-D image arrays with geographically fixed sample spacing ~1 arc-second (about 30 m) (TBC). The L2_HR_FPDEM raster product is generated on a geodetic latitude-longitude grid, and the pixel centers are aligned with the prime (Greenwich) meridian and the equator.

The elevation of each floodplain raster sample is aggregated from the height-constrained geolocations and elevations [1] of the water/land boundary pixels of the multitemporal stack of L2_HR_PIXCVec products [4] (the aggregation and interpolation processes are illustrated in Figure 3 and Figure 4, and further detailed in [2]). Geophysical correction and various other variables are retrieved from the corresponding L2_HR_PIXC products [3]. The posting of the pixels of these products is variable across the swath and in the order of 20 m (in average) in both directions [3] [4]. In terms of resolution, the smoothing performed when generating the

L2_HR_PIXC and L2_HR_PIXCVec products is designed to preserve the ability to resolve the boundaries of 50-100 m rivers [3] [4]. The posting is further densified when aggregating pixel cloud data over time, without necessarily improving the resolution, which depends on multiple factors including geolocation accuracy, how the floodplain is sampled by the water/land boundary pixels over time, etc. The actual resolution of the final raster floodplain DEM will also depend on the interpolation method used. It is expected to be in the order of 50-100 m.

A large part of the L2_HR_FPDEM raster pixels will be fill values (NoData). For many applications, users will need to combine the L2_HR_FPDEM with another DEM to complete it. A fixed standard grid will make this easier. It is particularly simple for the SRTM/NASADEM global DEM, as we have exactly the same tiling, sampling and reference system.

3.5 Temporal Organization

The floodplain DEM product is based on SWOT acquisitions aggregated over at least one year, from both ascending and descending passes, and does not have any temporal organization in itself. The time period covered by the SWOT data used to generate the product is given in the metadata.

3.6 Spatial Organization

The floodplain DEM raster (Gridded) files are organized as 2-D image arrays with fixed sample spacing in degrees. The image array coordinate indices increase from west to east and from south to north. The samples of the additional floodplain DEM pixel cloud (Ungridded) files for expert users are not spatially ordered.

3.7 Volume

The floodplain DEM product can only be computed between the minimum and maximum water elevation and extent observed by SWOT over the acquisition period. Elsewhere, the raster floodplain DEM files (Gridded) will be filled with NoData values. This means that only a small fraction of the full raster extent will contain valid data. Likewise, the floodplain DEM pixel cloud (Ungridded) will contain only a fraction of the input L2_HR_PIXC/L2_HR_PIXCVec pixels over the time period (water/land boundaries only).

Table 2. Description of the data volume of each file of the L2_HR_FPDEM product

File	Short name	Name	Expected Mean Volume/Granule (MB/tile)	Maximum Volume/Granule (MB/tile)	Total Volume (GB)
1	FPDEM_Gridded	Level 2 KaRIn high-rate gridded floodplain DEM	1.0	8.5	57.6
2	FPDEM_Ungridded	Level 2 KaRIn high-rate ungridded floodplain DEM	263	3 450	14 770

Table 2 provides the expected average volume of the individual files composing the L2_HR_FPDEM product. The estimated volumes are based on the following hypotheses:

- Considering that SWOT acquires data up to +/-78° latitude, and that each FPDEM tile covers 1°x1°, there will be altogether 360 x 156 = 56 160 FPDEM tiles.

- However, only ~24% of the SWOT coverage is acquired in HR mode (mainly continental surfaces).
- For the FPDEM_Gridded file:
  - With a sampling of 1 arcsecond (0.000277°), there will be 3600x3600 = 12 960 000 pixels per 1°x1°tile.
  - There are 7 variables with a total of 33 bytes per pixel (2x8+4x4+1).
  - We consider that only 1% (mean) or 2% (max) of a FPDEM raster will correspond to areas between the min and max water extent over continents (TBC). Outside the HR mask it will be 0%.
  - The expected mean volume per 1°x1° tile, including areas outside the HR mask, is therefore 12 960 000 pixels x 33 bytes per pixel x 1% x 24 % = 1.03 MB (and 12 960 000 pixels x 33 bytes per pixel x 1% = 4.3 MB for tiles within the HR mask)
  - The expected max volume per 1°x1° tile, that can only occur within the HR mask, becomes 12 960 000 pixels x 33 bytes per pixel x 2% = 8.5 MB.
  - The expected total data volume becomes 1.03 MB x 56 160 = 57 644 MB.
- For the FPDEM_Ungridded file:
  - For the 22-day science orbit there are 584 passes x 308 tiles x 2 swaths = 359 744 64x64 km^2 tile granules per cycle. However, L2_HR_PIXC/L2_HR_PIXCVec products are only generated within the HR mask, which implies that there will be around 86 120 actual L2_HR_PIXC/L2_HR_PIXCVec tiles (24%) per cycle.
  - We consider the final FPDEM produced after 3 years on the science orbit, which will be based on 3 x 365/22* 86 120 = 4 286 427 L2_HR_PIXC/L2_HR_PIXCVec tiles.
  - This means that we will have on the average 4 286 427 / 56 160 = 76,3 actual L2_HR_PIXC/L2_HR_PIXCVec tiles per L2_HR_FPDEM when considering all 1°x1° tiles including those outside the HR mask for the latter, and roughly 76,3 / 24% = 318 L2_HR_PIXC/L2_HR_PIXCVec tiles per L2_HR_FPDEM tile if we only consider L2_HR_FPDEM tiles that are within the HR mask (i.e. not void).
  - However, the number of L2_HR_PIXC/L2_HR_PIXCVec tiles per L2_HR_FPDEM tile will vary with latitude, from about 150 near the equator to about 1000 at high latitude (TBC).
  - The number of pixels per full 64x64 km^2 tile would be 3000 x 4600 = 13 800 000, which with a conservative hypothesis of 10% water for a given L2_HR_PIXC/L2_HR_PIXCVec tile, and 1% (mean) and 2% (max) water/land boundary pixels, yields 138 000 (mean) or 276 000 (max) boundary pixels per L2_HR_PIXC/L2_HR_PIXCVec tile.
  - The FPDEM_Ungridded product will have 6 variables, with a total of 25 bytes per pixel (2x8+2x4+1).
  - The expected mean volume per 1°x1° FPDEM_Ungridded tile (including those outside the HR mask), is therefore 76,3 L2_HR_PIXC/L2_HR_PIXCVec tiles x 138 000 pixels x 25 bytes per pixel = 263 MB (and roughly 263 MB / 24% = 1 096 MB if we only consider FPDEM_Ungridded tiles within the HR mask).
  - The expected max volume per 1°x1° tile, that will occur within the HR mask and typically at high latitude, becomes about 1000 L2_HR_PIXC/L2_HR_PIXCVec tiles x 138 000 pixels x 25 bytes per pixel = 3 450 MB.
  - The expected total data volume becomes 263 MB x 56 160 = 14 770 080 MB.

4 Qualitative Description

The L2_HR_FPDEM product represents a floodplain DEM (partial bathymetry) derived from the multi-temporal stack of L2_HR_PIXC and L2_HR_PIXCVec products, using the so-called bathtub ring approach introduced in Section 2.1.

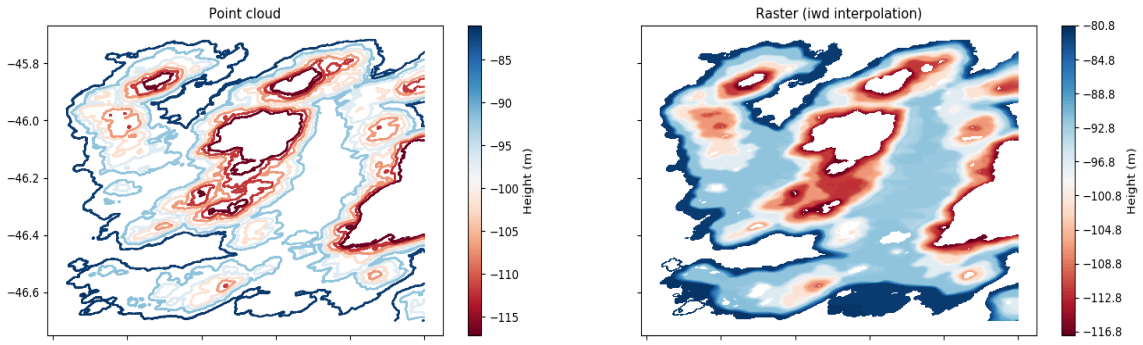
As illustrated in Figure 1 (b) and in Figure 3, and further detailed in [2], the first step of the floodplain DEM processing is to aggregate a multi-temporal point cloud of water/land boundary pixels that are assumed to represent bathymetry information. More specifically these are pixels labeled as *water_near_land* or *low_coh_water_near_land* in the L2_HR_PIXC *classification* variable [3], and having one or more 4-neighborhood pixels labelled as *land_near_water*. Thereafter, filtering of outliers and interpolation is performed to obtain the raster (Gridded) floodplain DEM product [2]. The intermediate pixel cloud data will be stored in a separate file (Ungridded) as described in Section 3.3, mainly to allow expert users to extract a floodplain DEM raster over a limited time period or at a different resolution, or to correct outliers and anomalies in a different way, or to analyze in more detail the topography observed in the raster floodplain DEM.

The main information in the L2_HR_FPDEM raster is the elevation of each pixel in the latitude/longitude raster grid, which is only provided in the area between the observed minimum and maximum water body elevation and extent in the acquisition period. The uncertainty of the floodplain DEM elevations and other quality indicators are also provided.

The quality of the floodplain DEM product depends on several factors:

- The random and systematic errors of the L2_HR_PIXC and L2_HR_PIXCVec products used (errors in the computed water surface extent and elevation)
- The number of acquisitions in a given area
- The observed variations in water elevation and extent, i.e. how well the stages between the observed min and max water levels are sampled (It is more difficult to extract precise bathymetry for steep banks than for more moderate floodplain topography.)

The L2_HR_FPDEM raster and pixel cloud data are stored in separate netCDF files corresponding to a 1°x1° tile. Each file contains a number of global attributes and a set of NetCDF variable layers.



(a) **(b)**

Figure 3. Example of (a) the multi-temporal boundary pixel point cloud (Ungridded) and (b) the final raster floodplain DEM product (Gridded), for a synthetic scene.

4.1 Gridded Floodplain DEM File

4.1.1 Global Attributes

A complete list of global attributes for the raster (Gridded) file of the Floodplain DEM product is given in section 5.2.1. In addition to common global attributes, there is an attribute that describe spatial sampling:

- *sampling*: Sampling of the data in degrees. The sampling in latitude is always the same as the sampling in longitude

4.1.2 Variables

The floodplain DEM raster data consist of one scalar coordinate reference system variable, two 1-D coordinate vectors, and a number of 2-D image variables. All 2-D image variables contained within the L2_HR_FPDEM product files are sampled evenly in the same Coordinate Reference System (CRS). The coordinate reference system and reference datum parameters are provided as a collection of attributes associated with the dimensionless (i.e., empty) *crs* attribute. The associated *crs* attributes are given in Table 7.

• *crs*: Coordinate reference system of the product. This is a dimensionless variable containing coordinate reference system parameters as variable attributes.

The L2_HR_ FPDEM product contains two 1-D coordinate vectors to define the gridded sampling locations of the raster pixels:

- *longitude, latitude*: Geodetic longitude and latitude coordinates giving the horizontal location of the center of the raster pixel. The latitude is a geodetic latitude with respect to the reference ellipsoid, which is defined by the *semi_major_axis* and *inverse_flattening* attributes of the *crs* variable. Positive latitude values increase northward from the equator. Positive longitude values increase eastward from the prime meridian.

The main floodplain DEM variable is the geodetic elevation, extracted from the different water surface elevations (wse) of the water/land boundary pixels. By aggregating and interpolating elevations from all passes and cycles, we estimate a representation of the bathymetry. Some quality indicators and other quantities are also provided.

The 2-D layers are:

- *elevation, elevation_uncert*: Elevation of the bathymetry, and its associated 1-sigma uncertainty. The elevation is reported relative to the geoid. It is computed by aggregating (inverse distance weighted interpolation) the geolocated elevations reported in the L2_HR_PIXCVec product water/land boundary pixels after applying corrections for geophysical effects. Specifically, height_vectorproc from the L2_HR_PIXCVec product is corrected for geoid height with respect to the reference ellipsoid, the solid earth tide, the load tide, and the pole tide (*geoid*, *solid_tide*, *load_tide_fes*, and *pole_tide* from the L2_HR_PIXC product, respectively). Note that height_vectorproc from the L2_HR_PIXCVec product has already been corrected for media delays (wet and dry troposphere and ionosphere) and the crossover calibration correction.

- *distance_to_closest*: The distance in meters to the closest L2_HR_PIXCVec water/land boundary pixel. A small value means that the rasterized pixel's geolocated elevation is close to the SWOT measurement itself; a large value means that the estimated elevation is interpolated from L2_HR_PIXCVec pixels that are further away.
- *mean_distance*: The mean distance in meters to the aggregated L2_HR_PIXCVec water/land boundary pixels.
- *fpdem_gridded_qual* : A quality indicator of the pixel, according to the number of observed pixels and their uncertainties.

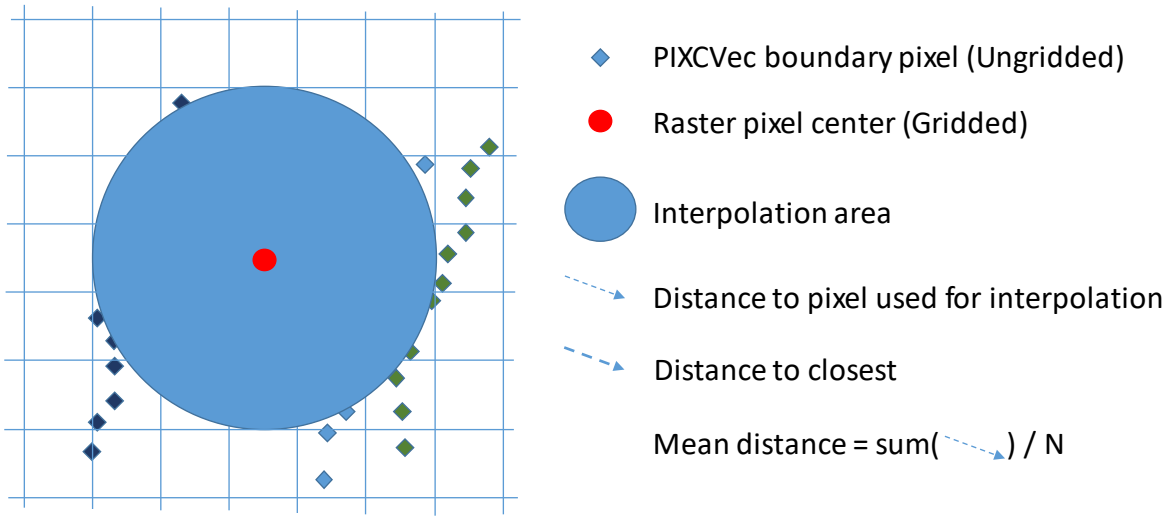


Figure 4. Illustration of the interpolation process and the computation of distances from PIXCVec water/land boundary pixels coming from different acquisitions/dates (shown with different colors).

4.2 Ungridded Floodplain DEM File

4.2.1 Global Attributes

A complete list of global attributes for the water/land boundary pixel cloud (Ungridded) file of the Floodplain DEM product is given in section 5.3.1. In addition to common global attributes, there are attributes that describe the data projection.

4.2.2 Variables

The Ungridded floodplain DEM data consist of one scalar coordinate reference system variable, and a number of 1-D image variables.

The different layers are described below:

- *crs*: Coordinate reference system of the product. This is a dimensionless variable containing coordinate reference system parameters as variable attributes.
- *longitude, latitude*: Geodetic longitude and latitude coordinates giving the horizontal

location of the center of the pixel. The latitude is a geodetic latitude with respect to the reference ellipsoid, which is defined by the *semi_major_axis* and *inverse_flattening* attributes of the *crs* variable. Positive latitude values increase northward from the equator. Positive longitude values increase eastward from the prime meridian.

- *elevation*: Surface elevation of the pixel relative to the geoid with the same geophysical corrections applied as *elevation* from the Gridded floodplain DEM file.
- *fpdem_ungridded_qual:* Flag to indicate if the pixel is valid and can be used to produce floodplain DEM raster
- *time*: measurement time of the pixel in UTC time scale, rounded to entire hours since January 1, 2000 00:00:00 UTC. It is computed by dividing the *illumination_time* (in seconds) of the same pixel in the input L2_HR_PIXC product by 3600, and rounding the result to entire hours. At the hour scale, it is not necessary to take leap seconds into account, so the corresponding TAI time is not provided in this product. The goal of the *time* variable is to allow expert users to filter the water/land boundary pixels by date, to make their own floodplain DEM over a more limited time period (e.g. a year, or a few months), which can be of interest in areas where the bathymetry changes rapidly.

5 Detailed Product Description

5.1 NetCDF Variables

Variables are used to store the various measurements. Each variable is assigned a name and a particular data type. Variables can be scalar values (i.e. 0 dimension), or can have one or more dimensions. Each variable then has attributes that provide additional information about the variable. Table 3 below identifies the data types used in the L2_HR_FPDEM SDP, and

Table 4 identifies the attributes that may be assigned to each variable.

Table 3. Variable data types in NetCDF products

Data Type	Description
char	characters
byte	8-bit signed integer
unsigned byte	8-bit unsigned integer
short	16-bit signed integer
unsigned short	16-bit unsigned integer
int	32-bit signed integer
unsigned int	32-bit unsigned integer
long	64-bit signed integer
unsigned long	64-bit unsigned integer
float	IEEE single precision floating point (32 bits)
double	IEEE double precision floating point (64 bits)

Table 4. Common variable attributes in NetCDF files.

Attribute	Description
_FillValue	The value used to represent missing or undefined data. (Before applying add_offset and scale_factor).
add_offset	If present, this value should be added to each data element after it is read. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
calendar	Reference time calendar
comment	Miscellaneous information about the data or the methods to generate it.
coordinates	Coordinate variables associated with the variable
flag_meanings	Used in conjunction with flag_values. Describes the meanings of each of the elements of flag_values.
flag_values	Used in conjunction with flag_meanings. Possible values of the flag variable.
institution	Institution which generates the source data for the variable, if applicable.
leap_second	UTC time at which a leap second occurs within the time span of data within the file.
long_name	A descriptive variable name that indicates its content.
quality_flag	Names of variable quality flag(s) that are associated with this variable to indicate its quality.
scale_factor	If present, the data are to be multiplied by the value after they are read. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
source	Data source (model, author, or instrument)
standard_name	A standard variable name that indicates its content.

tai_utc_difference	Difference between TAI and UTC reference time.
units	Unit of data after applying offset (add_offset) and scale_factor.
valid_max	Maximum theoretical value of variable before applying scale_factor and add_offset (not necessarily the same as maximum value of actual data)
valid_min	Minimum theoretical value of variable before applying scale_factor and add_offset (not necessarily the same as minimum value of actual data)

5.2 Level 2 High Rate Gridded Floodplain DEM file

5.2.1 Global Attributes

Global attributes are provided in Table 5.

Table 5. Global attributes for L2_HR_FPDEM_Gridded files

Attribute	Format	Description
Conventions	string	NetCDF-4 conventions adopted in this group. This attribute should be set to CF-1.7 to indicate that the group is compliant with the Climate and Forecast NetCDF conventions.
title	string	Level 2 KaRIn High Rate FPDEM Gridded Data Product
institution	string	Name of producing agency.
source	string	The method of production of the original data. If it was model-generated, source should name the model and its version, as specifically as could be useful. If it is observational, source should characterize it (e.g., 'Ka-band radar interferometer').
history	string	UTC time when file generated. Format is: 'YYYY-MM-DDThh:mm:ssZ : Creation'
platform	string	SWOT
references	string	Published or web-based references that describe the data or methods used to produce it. Provides version number of software generating product.
reference_document	string	Name and version of Product Description Document to use as reference for product.
contact	string	Contact information for producer of product. (e.g., 'ops@jpl.nasa.gov').
coordinate_reference_system	string	Name of the coordinate reference system.
sampling	float	Raster grid sampling. Units depend on the coordinate reference system.
short_name	string	L2_HR_FPDEM_Gridded
descriptor_string	string	<NorthingCoordinatesWrtEquator>_ <EastingCoordinatesWrtGreenwichMeridian>
crid	string	Composite release identifier (CRID) of the data system used to generate this file
product_version	string	Version identifier of this data file
pge_name	string	Name of the product generation executable (PGE) that created this file
pge_version	string	Version identifier of the product generation executable (PGE) that created this file
time_coverage_start	string	UTC time of first measurement. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
time_coverage_end	string	UTC time of last measurement. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
geospatial_lon_min	double	Westernmost longitude (deg) of FPDEM sampling grid.
geospatial_lon_max	double	Easternmost longitude (deg) of FPDEM sampling grid.

geospatial_lat_min	double	Southernmost latitude (deg) of FPDEM sampling grid.
geospatial_lat_max	double	Northernmost latitude (deg) of FPDEM sampling grid.
xref_input_l2_hr_pixc_files	string	List of input Level 2 KaRIn high rate water mask pixel cloud product files.
xref_input_l2_hr_pixcvec_files	string	List of input Level 2 KaRIn high rate pixel cloud vector attribute files.

5.2.2 Dimensions

The L2_HR_FPDEM_Gridded NetCDF files use the dimensions attributes to identify the physical dimensions of variables within the file.

Table 6. Variable dimensions for L2_HR_FPDEM_Gridded files

Name	Description
longitude	The number of longitude coordinate pixels for each 2-D image variable.
latitude	The number of latitude coordinate pixels for each 2-D image variable.

5.2.3 Variables

Table 7. Variables of L2_HR_FPDEM_Gridded files

Variables		
char crs()		
	_FillValue	*
	long_name	CRS Definition
	grid_mapping_name	latitude_longitude
	geographic_crs_name	[OGS geographic CRS name]
	reference_ellipsoid_name	[Reference ellipsoid name]
	horizontal_datum_name	[Horizontal datum name]
	prime_meridian_name	[Prime meridian name]
	longitude_of_prime_meridian	[Longitude of prime meridian]
	semi_major_axis	[Ellipsoid semi-major axis]
	inverse_flattening	[Ellipsoid inverse flattening]
	crs_wkt	[OGS Well-Known Text string]
	spatial_ref	[OGS Well-Known Text string]
	comment	Geodetic latitude/longitude coordinate reference system.
double longitude(longitude)		
	_FillValue	9.969209968386869e+36
	long_name	longitude (degrees East)
	standard_name	longitude
	units	degrees_east
	valid_min	-180
	valid_max	180
	comment	Longitude [-180,180) (east of the Greenwich meridian) of the pixel.
double latitude(latitude)		
	_FillValue	9.969209968386869e+36
	long_name	latitude (positive N, negative S)
	standard_name	latitude
	units	degrees_north
	valid_min	-80
	valid_max	80

	comment	Latitude [-80,80] (degrees north of equator) of the pixel.
float elevation(longitude, latitude)		
	_FillValue	9.96921e+36
	long_name	surface elevation above geoid
	grid_mapping	crs
	units	m
	valid_min	-1500
	valid_max	15000
	coordinates	[longitude] [latitude]
	comment	Surface elevation of the pixel above the geoid and after using models to subtract the effects of tides (solid_earth_tide, load_tide_fes, pole_tide).
float elevation_uncert(ongitude, latitude)		
	_FillValue	9.96921e+36
	long_name	uncertainty in the surface elevation
	grid_mapping	crs
	units	m
	valid_min	0
	valid_max	999999
	coordinates	[longitude] [latitude]
	comment	1-sigma uncertainty in the surface elevation.
float distance_to_closest(longitude, latitude)		
	_FillValue	9.96921e+36
	long_name	distance to closest boundary pixel
	grid_mapping	crs
	units	m
	valid_min	0
	valid_max	999999
	coordinates	[longitude] [latitude]
	comment	Distance to closest boundary pixel
float mean_distance (longitude, latitude)		
	_FillValue	9.96921e+36
	long_name	mean distance to selected boundary pixels
	grid_mapping	crs
	units	m
	valid_min	0
	valid_max	999999
	coordinates	[longitude] [latitude]
	comment	Mean distance to selected boundary pixels
unsigned byte fpdem_gridded_qual (longitude, latitude)		
	_FillValue	255
	long_name	gridded floodplain DEM quality flag
	grid_mapping	crs
	units	1
	flag_meanings	good bad
	flag_values	0 1
	valid_min	0
	valid_max	1
	coordinates	[longitude] [latitude]
	comment	Gridded floodplain DEM quality flag

5.3 Level 2 High Rate Ungridded Floodplain DEM file

5.3.1 Global Attributes

Global attributes are provided in Table 8.

Table 8. Global attributes for L2_HR_FPDEM_Ungridded product files

Attribute	Format	Description
Conventions	string	NetCDF-4 conventions adopted in this group. This attribute should be set to CF-1.7 to indicate that the group is compliant with the Climate and Forecast NetCDF conventions.
title	string	Level 2 KaRIn High Rate FPDEM Ungridded Data Product
institution	string	Name of producing agency.
source	string	The method of production of the original data. If it was model-generated, source should name the model and its version, as specifically as could be useful. If it is observational, source should characterize it (e.g., 'Ka-band radar interferometer').
history	string	UTC time when file generated. Format is: 'YYYY-MM-DDThh:mm:ssZ : Creation'
platform	string	SWOT
references	string	Published or web-based references that describe the data or methods used to produce it. Provides version number of software generating product.
reference_document	string	Name and version of Product Description Document to use as reference for product.
contact	string	Contact information for producer of product. (e.g., 'ops@jpl.nasa.gov').
coordinate_reference_system	string	Name of the coordinate reference system.
short_name	string	L2_HR_FPDEM_Ungridded
descriptor_string	string	<NorthingCoordinatesWrtEquator>_ <EastingCoordinatesWrtGreenwichMeridian>
crid	string	Composite release identifier (CRID) of the data system used to generate this file
product_version	string	Version identifier of this data file
pge_name	string	Name of the product generation executable (PGE) that created this file
pge_version	string	Version identifier of the product generation executable (PGE) that created this file
time_coverage_start	string	UTC time of first measurement. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
time_coverage_end	string	UTC time of last measurement. Format is: YYYY-MM-DDThh:mm:ss.ssssssZ
geospatial_lon_min	double	Westernmost longitude (deg) of FPDEM sampling grid.
geospatial_lon_max	double	Easternmost longitude (deg) of FPDEM sampling grid.
geospatial_lat_min	double	Southernmost latitude (deg) of FPDEM sampling grid.
geospatial_lat_max	double	Northernmost latitude (deg) of FPDEM sampling grid.
xref_input_l2_hr_pixc_files	string	List of input Level 2 KaRIn high rate water mask pixel cloud product files.
xref_input_l2_hr_pixcvec_files	string	List of input Level 2 KaRIn high rate pixel cloud vector attribute files.

5.3.2 Dimensions

The L2_HR_FPDEM_Ungridded NetCDF files use the index attributes to identify the physical dimensions of variables within the file.

Table 9. Variable dimensions for L2_HR_FPDEM_Ungridded files

Name	Description
index	Index of the pixel

5.3.3 Variables

Table 10. Variables of L2_HR_FPDEM_Ungridded files

Variables		
char crs()		
	_FillValue	*
	long_name	CRS Definition
	grid_mapping_name	latitude_longitude
	geographic_crs_name	[OGS geographic CRS name]
	reference_ellipsoid_name	[Reference ellipsoid name]
	horizontal_datum_name	[Horizontal datum name]
	prime_meridian_name	[Prime meridian name]
	longitude_of_prime_meridian	[Longitude of prime meridian]
	semi_major_axis	[Ellipsoid semi-major axis]
	inverse_flattening	[Ellipsoid inverse flattening]
	crs_wkt	[OGS Well-Known Text string]
	spatial_ref	[OGS Well-Known Text string]
	comment	Geodetic latitude/longitude coordinate reference system.
double longitude(index)		
	_FillValue	9.969209968386869e+36
	long_name	longitude (degrees East)
	standard_name	longitude
	units	degrees_east
	valid_min	-180
	valid_max	180
	comment	Longitude [-180,180) (east of the Greenwich meridian) of the pixel.
double latitude(index)		
	_FillValue	9.969209968386869e+36
	long_name	latitude (positive N, negative S)
	standard_name	latitude
	units	degrees_north
	valid_min	-80
	valid_max	80
	comment	Latitude [-80,80] (degrees north of equator) of the pixel.
float elevation(index)		
	_FillValue	9.96921e+36
	long_name	surface elevation above geoid
	grid_mapping	crs
	units	m
	valid_min	-1500
	valid_max	15000

	comment	Surface elevation of the pixel above the geoid and after using models to subtract the effects of tides (solid_earth_tide, load_tide_fes, pole_tide).
unsigned byte fpdem_ungridded_qual(index)		
	_FillValue	255
	long_name	ungridded floodplain DEM quality flag
	grid_mapping	crs
	units	1
	flag_meanings	good suspect bad
	flag_values	0 1 2
	valid_min	0
	valid_max	2
	comment	Ungridded floodplain DEM quality flag computed as the maximum of the three quality flags of the pixel in the corresponding L2_HR_PIXC product.
int time(index)		
	_FillValue	2147483647
	long_name	measurement time in hours (UTC)
	grid_mapping	crs
	units	hours
	valid_min	175320
	valid_max	438300
	comment	Time of measurement in hours in the UTC time scale since 1 Jan 2000 00:00:00 UTC, obtained by dividing the illumination_time (in seconds) of the pixel in the L2_HR_PIXC product by 3600, and rounding it to entire hours.

6 References

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[3] B. A. Williams, "Product Description, Level 2 KaRIn high rate water mask pixel cloud product," Jet Propulsion Laboratory, D-56411, 2022.

[4] C. Pottier, "Product Description Document, Level 2 KaRIn high rate pixel cloud vector attribute product," Centre National d'Études Spatiales, SWOT-TN-CDM-0677-CNES, 2022.

[5] N. JPL, "NASADEM Merged DEM Global 1 arc second V001," NASA EOSDIS Land Processes DAAC, 2020. [Online]. Available: https://doi.org/10.5067/MEaSUREs/NASADEM/NASADEM_HGT.001.

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
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator