Delta-X: AirSWOT Level 1B Interferogram Products in Radar Coordinates, 2021

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Documentation Revision Date: 2022-08-29

Dataset Version: 1.1

Summary

This dataset contains AirSWOT interferogram products collected during the 2021 Delta-X Campaign over the Atchafalaya and Terrebonne Basins of the Mississippi River Delta, Louisiana, USA from 2021-03-26 to 2021-04-18 (Spring) and 2021-08-21 to 2021-09-12 (Fall). AirSWOT uses near-nadir wide-swath Ka-band radar interferometry to measure water-surface elevation and produce continuous gridded elevation data. AirSWOT elevation data is useful for calibrating elevation and slopes along the main channels, as well as tying observations to open ocean tidal conditions. The AirSWOT Level 1B (L1B) data products represent interferogram data in the radar coordinate system, not in georeferenced map coordinates. This is an earlier stage of data processing which is used to generate the later Level 2 and Level 3 data products which will contain georeferenced water heights and water height profiles for river channels in each basin. The data are provided in binary and text file formats.

Delta-X conducted a joint airborne and field campaign in the Mississippi River Delta during Spring and Fall 2021. The Delta-X campaign conducted airborne (remote sensing) and field (in situ) measurements to observe hydrology, water quality (e.g., total suspended solids (TSS)) and vegetation structure.

This dataset includes a total of 6,210 files in binary and text formats. There are 414 data acquisitions with 15 files per acquisition.

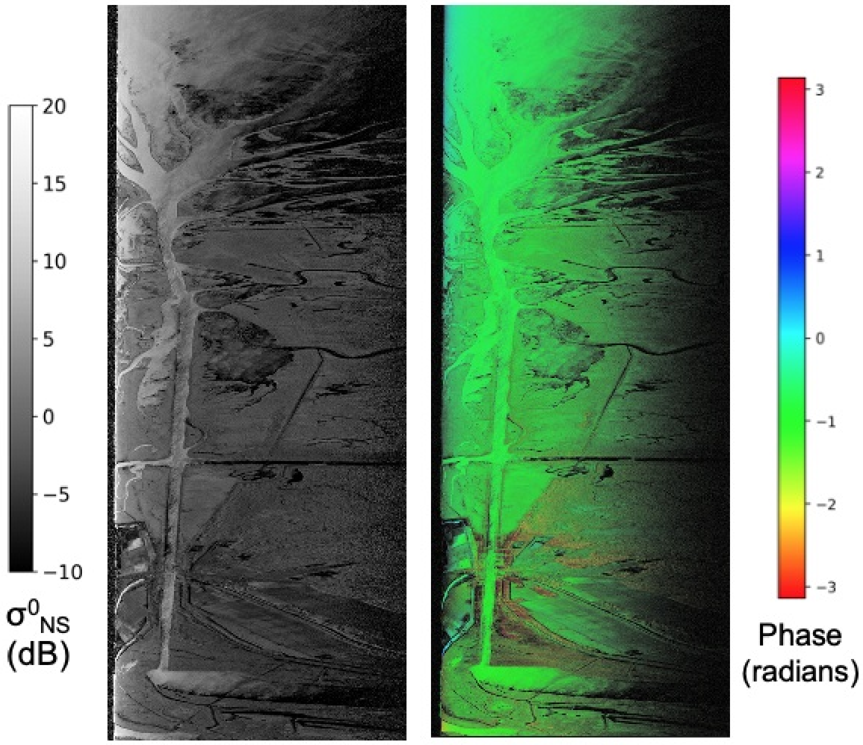

Figure 1. AirSWOT L1B noise-subtracted reference power (left image) and complex interferogram (right image) collected on April 1, 2021 (Flight Line ID: 124406). In the complex interferogram image, the brightness of each pixel corresponds to the interferogram coherence magnitude, while the color of each pixel corresponds to the interferogram phase (as shown in the colorbar).

Citation

Denbina, M.W., M. Simard, and E. Rodriguez. 2021. Delta-X: AirSWOT Level 1B Interferogram Products in Radar Coordinates, 2021. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1996

Table of Contents

1. Dataset Overview

This dataset contains AirSWOT interferogram products collected during the 2021 Delta-X Campaign over the Atchafalaya and Terrebonne Basins of the Mississippi River Delta, Louisiana, USA from 2021-03-26 to 2021-04-18 (Spring) and 2021-08-21 to 2021-09-12 (Fall). AirSWOT uses near-nadir wide-swath Ka-band radar interferometry to measure water-surface elevation and produce continuous gridded elevation data. AirSWOT elevation data is useful for calibrating elevation and slopes along the main channels, as well as tying observations to open ocean tidal conditions. The AirSWOT Level 1B (L1B) data products represent interferogram data in the radar coordinate system, not in geocoded map coordinates. This is an earlier stage of data processing which is used to generate the later Level 2 and Level 3 data products which will contain geocoded water heights and water height profiles for river channels in each basin.

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Project: Delta-X

The Delta-X mission is a 5-year NASA Earth Venture Suborbital-3 mission to study the Mississippi River Delta in the United States, which is growing and sinking in different areas. River deltas and their wetlands are drowning as a result of sea level rise and reduced sediment inputs. The Delta-X mission will determine which parts will survive and continue to grow, and which parts will be lost. Delta-X begins with airborne and in situ data acquisition and carries through data analysis, model integration, and validation to predict the extent and spatial patterns of future deltaic land loss or gain.

Related Publications

Denbina, M., M. Simard, E. Rodriguez, X. Wu, A. Chen, and T. Pavelsky. 2019. Mapping water surface elevation and slope in the Mississippi River Delta Using the AirSWOT Ka-band interferometric synthetic aperture radar. Remote Sensing 11:2739. https://doi.org/10.3390/rs11232739

Related Datasets

Denbina, M.W., M. Simard, E. Rodriguez, X. Wu, and C. Michailovsky. 2021. Pre-Delta-X: L2 AirSWOT Water Surface Elevations, Atchafalaya Basin, LA, USA, 2016. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1818

Acknowledgments

This work was supported by NASA's Earth Venture Suborbital-3 (EVS-3) program (NNH17ZDA001N-EVS3).

2. Data Characteristics

Spatial Coverage: Atchafalaya and Terrebonne Basins, southern coast of Louisiana, USA

Spatial Resolution: approximately 3 m

Temporal Coverage: 2021-03-26 to 2021-04-18 (Spring) and 2021-08-21 to 2021-09-12 (Fall)

Temporal Resolution: Repeated samples during acquisition flights at 5 to 10-minute intervals

Site Boundaries: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Atchafalaya and Terrebonne Basins	-91.5375	-90.5819	29.7903	29.0714

Data File Information

This dataset includes a total of 6,210 files in binary and text formats. There are 414 data acquisitions with 15 files per acquisition (Table 1).

The files are named **int_m0_<site><YYYYMMDD>_<hhmmss>.<ext>** (e.g., int_m0_WTerre20210418_202023.int), where

- <site> = site name: "Atcha" = Atchafalaya basin, "ETerre" = east Terrebonne basin, "WTerre" = west Terrebonne basin
- <YYYYMMDD> = flight date in UTC year (YYYY), month (MM) and day (DD).
- <hhmmss> = flight time in UTC hour (hh), minute (mm), and second (ss)
- <ext> = file type described in Table 1.

The radar coordinate system includes the S (along-track), C (cross-track), and H (spherical height) coordinates. The parameters of the SCH coordinate system are described in the **.schdem_par* file for each acquisition. These L1B files are not georeferenced, although preliminary geographic coordinates are included in the **.aux* and **.llhe* files.

The **.schdem_par*, **.par*, and **.aux* files contain plain-text metadata needed for interpreting the other flat binary files.

- The **.schdem_par* contains the image dimensions of the **.schdem* file.
- The **.aux* file is a space-delimited plain text file containing aircraft position and attitude information for each radar pulse used to form the interferogram.
- The **.par* file contains the image dimensions of the following binary rasters: **.int, *.int.unw, *.inc, *.ela, *.dhdphi, *.int.sch, *.llhe, *.refp_cal, *.refp_cal_ns, *.secp_cal*, and **.secp_cal_ns*. Note that the **.llhe* and **.int.sch* files are multi-channel files, while the other files are single-channel. The **.par* file also contains the slant range of the first range index in the interferogram (near_range) and the range spacing

(range_spacing), both in meters.

Attributes in the **.par* file allow the user to determine which row of the **.aux* file corresponds to each image line. For example, if the parameter first_image_line_tvp_index equals 5000, the first image line corresponds to the 5000th row of data in the **.aux* file. The nr_tvps_per_image_line for these products equals 50, the number of along-track looks (azimuth_looks in the **.par* file) used when forming the interferograms. For each successive image line in the interferogram, the corresponding index_number in **.aux* increases by 50 samples. To calculate which row in the **.aux* file corresponds to a given interferogram image line, use the following equation with values from **.par*:

index_number = first_image_line_tvp_index + (image line – 1) * nr_tvps_per_image_line ,

where index_number is in the first column of each data row in the **.aux* file.

Table 1. File types and descriptions.

File extension	Description	Variables	Units	Datatype	Dimensions
aux	Aircraft position, attitude, velocity, and acceleration for each collected radar profile. The first row describes the ellipsoid semi-major axis and squared eccentricity of the WGS84 ellipsoid used in processing. The second row describes the peg latitude, longitude, and heading of the SCH coordinate system used in processing. Remaining rows contain space-delimited variables.	index_number, profile_number	unitless	Text	-
		UTC time	seconds since 00:00:00		
		Latitude, longitude, altitude (m)	degrees, m		
		Pitch, heading, wander	degrees		
		Position in radar coordinates: S, C, H	m		
		Velocity in S, C, H directions	m s-1		
		Acceleration in S, C, H directions	m s-2		
dhdphi	Vertical height sensitivity to interferometric phase: the amount of vertical height corresponding to 1 radian of interferometric phase difference, which depends on the viewing and target geometry.	Vertical height sensitivity to interferometric phase	m radians-1	Float32	nr_lines, nr_pixels; from *par* file.
ela	Antenna elevation angle: the cross-track elevation angle between the radar look vector and the aircraft nadir, as measured at the antenna.	Angle	radians	Float32	nr_lines, nr_pixels; from *par* file.
inc	Incidence angle estimated from the reference digital elevation model (DEM)	Incidence angle	radians	Float32	nr_lines, nr_pixels; from *par* file.
int	Complex-valued interferogram: magnitude represents the coherence magnitude between the SAR acquisitions used to form the interferogram while the phase represents the interferogram phase.	Interferogram	1	Complex64	nr_lines, nr_pixels; from *par* file.
intsch	Digital elevation model (DEM) projected into SCH radar coordinates; 3-channel raster with dimensions from par file.	S coordinate, C coordinate, H spherical height	m	Float32	nr_lines, nr_pixels, 3; from *par* file.
intunw	Unwrapped phase of the interferogram	Interferogram phase	radians	Float32	nr_lines, nr_pixels; from *par* file.
llhe	Estimated geolocation, height with respect to the ellipsoid, and 1-sigma height error for each pixel; 4 channel raster	Latitude, longitude,	radians	Float64	nr_lines, nr_pixels, 4; from *par* file.
		Height, height error	m	Float32	
par	Interferometric parameter file: data dimensions for multiple files.	number of image lines (nr_lines), number of image pixels (nr_pixels), first aux index used in interferogram (first_image_line_tvp_index), number of aux indices per interferogram image line (nr_tvps_per_image_line), umber of azimuth looks (azimuth_looks), and number of range looks (range_looks)	1	Text	-
		near_range, range_spacing	m		

refp_cal	Backscattered power measured at the reference antenna without noise subtraction	Linear power: sigma0_in_db	10 log10	Float32	nr_lines, nr_pixels; from *par* file.
refp_cal_ns	Backscattered power measured at the reference antenna after noise subtraction. Negative values indicate that observed power (backscatter) was below instrument noise.	Linear power: sigma0_in_db	10 log10	Float32	nr_lines, nr_pixels; from *par* file.
schdem	Digital elevation model (DEM) in SCH coordinate system used for interferogram processing	Spherical height	m	Float32	Number of lines, Number of pixels; from *schdem_par* file
schdem_par	SCH DEM parameter file: parameters of the SCH coordinate system, and the image dimensions of the schdem raster	-	-	Text	-
secp_cal	Backscattered power measured at the secondary antenna without noise subtraction	Linear power: sigma0_in_db	10 log10	Float32	nr_lines, nr_pixels; from *par* file.
secp_cal_ns	Backscattered power measured at the secondary antenna after noise subtraction. Negative values indicate that observed power (backscatter) was below instrument noise.	Linear power: sigma0_in_db	10 log10	Float32	nr_lines, nr_pixels; from *par* file.

3. Application and Derivation

AirSWOT is used to measure open water surface elevation, which serves to calibrate and validate hydrodynamic models and estimate river discharge. AirSWOT was developed in collaboration with the SWOT project and has supported multiple ocean and hydrology campaigns. In addition to the data from the pre-Delta-X campaign (Denbina et al., 2019), its performance has been demonstrated over the Tanana River (Altenau et al., 2017), the Yukon Flats Basin (Pitcher et al., 2019), and the Willamette River (Tuozzolo et al., 2019).

4. Quality Assessment

AirSWOT produces continuous gridded elevation data. On a pixel basis, elevation error was dominated by random noise, and contiguous pixels along a river channel were averaged to reduce measurement noise. Other factors such as atmospheric delays, GPS errors, and instrument drift produce slowly varying errors that are corrected using in situ data (leveled pressure transducers, for Delta-X) and cross-over calibration from overlapping flight lines. The combined measurement system yields errors smaller than 1 cm/km over 10-km reaches, which is close to a factor of 2 better than required for Delta-X. Assuming a total averaging area of 1 km^2, the height noise was less than 10 cm for the Pre-Delta-X L2 products after final phase calibration. However, this dataset represents an earlier stage of processing where the height error could be more significant and has not yet been quantified or assessed.

An estimated height uncertainty is included for each image pixel in the **.llhe* file included in the L1B products. This product provides an estimate of the theoretical 1-sigma standard deviation of the AirSWOT height for each image pixel, calculated using the interferogram coherence and height-to-phase sensitivity. However, it should be noted that since this is an estimate of the random error due to interferometric decorrelation and phase noise, these values will not account for systematic errors which may be introduced by the imprecise phase calibration at this processing stage. Therefore, the heights and height errors in the **.llhe* file should be considered approximate values which are refined and improved in the L2 and L3 products. While these L1B data products are useful for analysis of backscatter and interferometric coherence, the water levels and heights in these products should be considered preliminary.

5. Data Acquisition, Materials, and Methods

AirSWOT uses near-nadir wide-swath radar interferometry (Rodriguez et al., 2017; Altenau et al., 2017) to measure water-surface elevation. The instrument operates at Ka-band (35.75 GHz), allowing for a compact antenna configuration using a ~1×1-m plate. The instrument includes six antennas that can form multiple baseline pairs for along-track and across-track interferometry. These antenna combinations provide contiguous coverage from about 500 m to 4 km from nadir, removing water-motion-induced geolocation and height errors. The instrument is coupled with a high-precision Applanix GPS/IMU system capable of high-precision trajectory reconstruction. The GPS/IMU data is used to compensate for the effects of aircraft motion and attitude of the radar data.

AirSWOT is designed for integration into the standard Avcon port in a KingAir B200 and has flown in the past on the NASA AFRC KA B200 (#801). For Delta-X, it is hosted on a Dynamic Aviation King Air. There are three components to the overall instrument suite: 1) radar mounted in the nadir forward port of the aircraft; 2) Avcon electronics rack in the main cabin; and 3) Welch power distribution rack in the rear of the aircraft. Integration requires two days. Two instrument operators are required in flight. Radiometric calibration data is acquired prior to deployment by imaging a corner reflector array in Rosamond, California, USA.

AirSWOT produces continuous gridded elevation data and data products in multiple modes. It employs cross-track and along-track interferometry to both estimate the height of the water surface and compensate for the motion of the water scatterers. The delivered products are from mode “m0”, which stands for mode 0 and represents the main cross-track outer swath mode of AirSWOT. Only outer swath products were included, and lines were processed using version 1.3 of the AirSWOT processing code. Data from this mode has also been used in other previous studies to measure water surface elevation and slope (e.g., Altenau et al., 2017; Altenau et al., 2019; Denbina et al., 2019; Pitcher et al., 2019; Tuozzolo et al., 2019).

AirSWOT performance in the floodplain was limited by the presence of vegetation and the very small slope characteristic of the two-dimensional floodplain discharge. Therefore, the bulk of the AirSWOT data collections were targeted at the larger channels because the channel discharge provides the necessary boundary conditions for potential overflow to islands and floodplains. The AirSWOT instrument suffered from small phase drifts creating potential slope artifacts in the cross-track direction. To correct the phase-drift artifacts, the flight pattern was designed to include crossovers that will be used to make global adjustments and estimate phase drifts when producing the L2 and L3 products. However, this refined calibration has not yet been applied to the L1B data located here; the data included in this package is from an earlier stage of processing before these corrections have been estimated or applied.

The phase drift compensation, with in situ water level measurements, was used to calibrate previous AirSWOT water surface level measurements from the Pre-Delta-X campaign (Denbina et al., 2019). The integration of in situ measurements into the AirSWOT processing was novel to the Pre-Delta-X campaign. In situ data were incorporated in the phase calibration procedure because the standard AirSWOT phase calibration could be adversely affected by vegetated areas such as wetlands, which cover a significant portion of the Delta-X study area (see Section 5 of Denbina, 2018).

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Delta-X: AirSWOT Level 1B Interferogram Products in Radar Coordinates, 2021

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

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8. Dataset Revisions

Version	Release Date	Revision Notes
1.1	2022-08-29	Fall 2021 data were added to the dataset. Dataset title and user guide were updated.
1.0		Initial release with Spring 2021 data only. (Preprint)