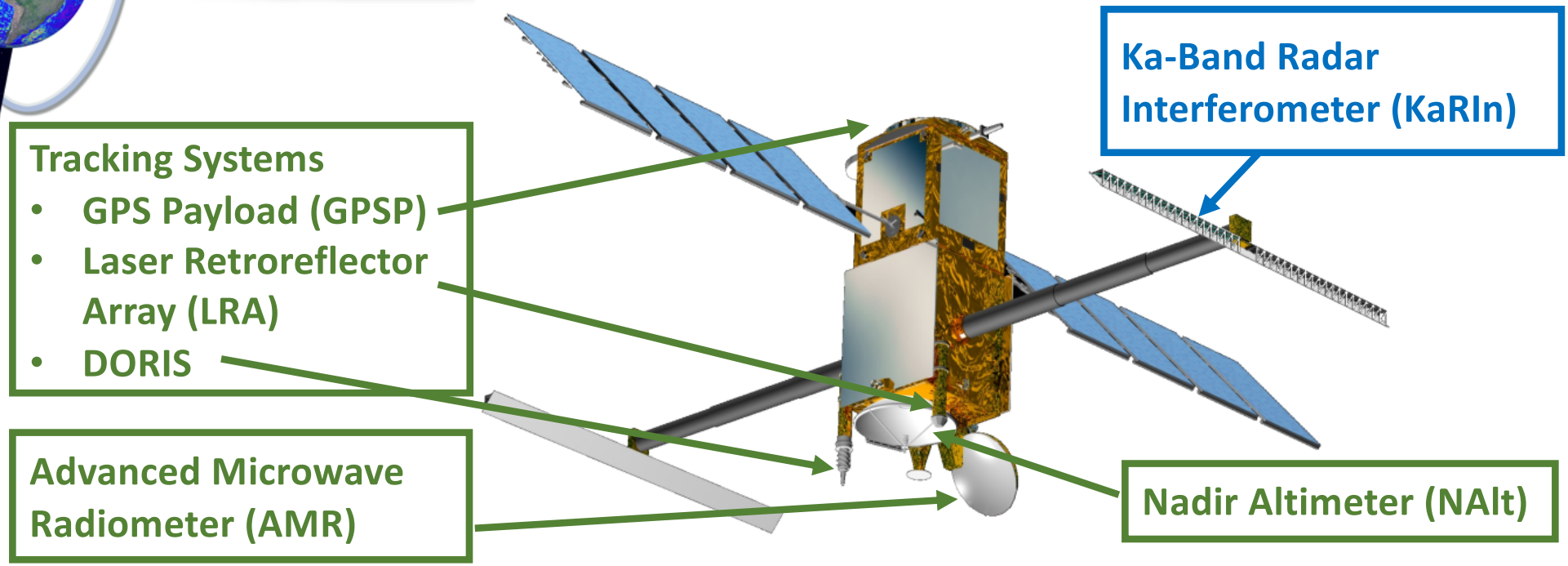
Surface Water and Ocean Topography (SWOT) Mission

February 9, 2021

SWOT Data Products

Shailen Desai[(1)], Nicolas Picot[(2)],
Curtis Chen[(1)], Roger Fjortoft[(2)], Alejandro Bohe[(2)]
on behalf of JPL/CNES Algorithm Development Team
[(1)]Jet Propulsion Laboratory, California Institute of Technology
[(2)]Centre National d'Etudes Spatiales

SWOT Science Data Products



- Two categories of SWOT science data products:
  - Products covering instruments with strong heritage:
    - NAlt, AMR, and tracking systems (DORIS, GPSP, LRA)
    - Based-upon best available Jason-3/Sentinel-6 standards.
  - Novel products from KaRIn:
    - Generally separated into ocean and hydrology products.

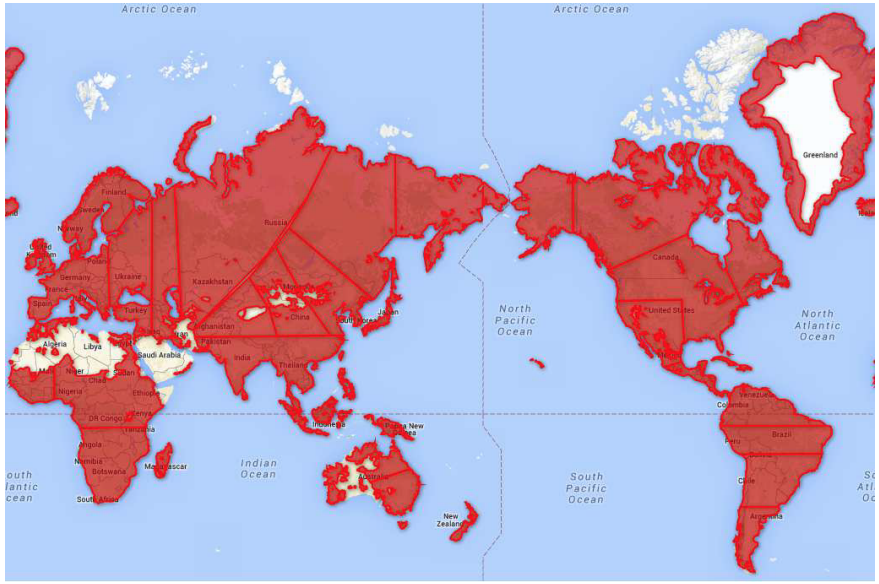
Heritage Science Products

Product	Description
L2_NALT_(O/I)GDR	Level 2 Nadir altimeter geophysical data record (GDR). Operational GDR with latency < 5 hours, Interim GDR with latency < 36 hours, GDR with latency < 90 days. Provides sea surface height, significant wave height, and sigma0 measurements at nadir.
L2_RAD_(O/I)GDR	Level 2 Radiometer geophysical data record (GDR). Operational GDR with latency < 5 hours, Interim GDR with latency < 36 hours, GDR with latency < 90 days. Provides wet troposphere delay and sigma0 atmospheric attenuation measurements over KaRIn swaths.
MOE/POE	Medium-Accuracy (< 36 hours) and Precise Orbit Ephemeris (< 28 days) products, providing satellite orbit position and velocity.
ATTD_RECONST	Reconstructed attitude data product, providing spacecraft orientation.
SAT_COM	Satellite center of mass product with position of center of mass relative to spacecraft reference point.
L1_DORIS_RINEX	Level 1 product providing tracking data from DORIS instrument in international RINEX format.
L1_GPSP_RINEX	Level 1 product providing tracking data from GPS Payload in international RINEX format.

- **Use best available product and algorithm standards from Jason-3 and Sentinel-6A, with similar latencies.**
  - Algorithms and products comprehensively reviewed by Ocean Surface Topography Science Team.

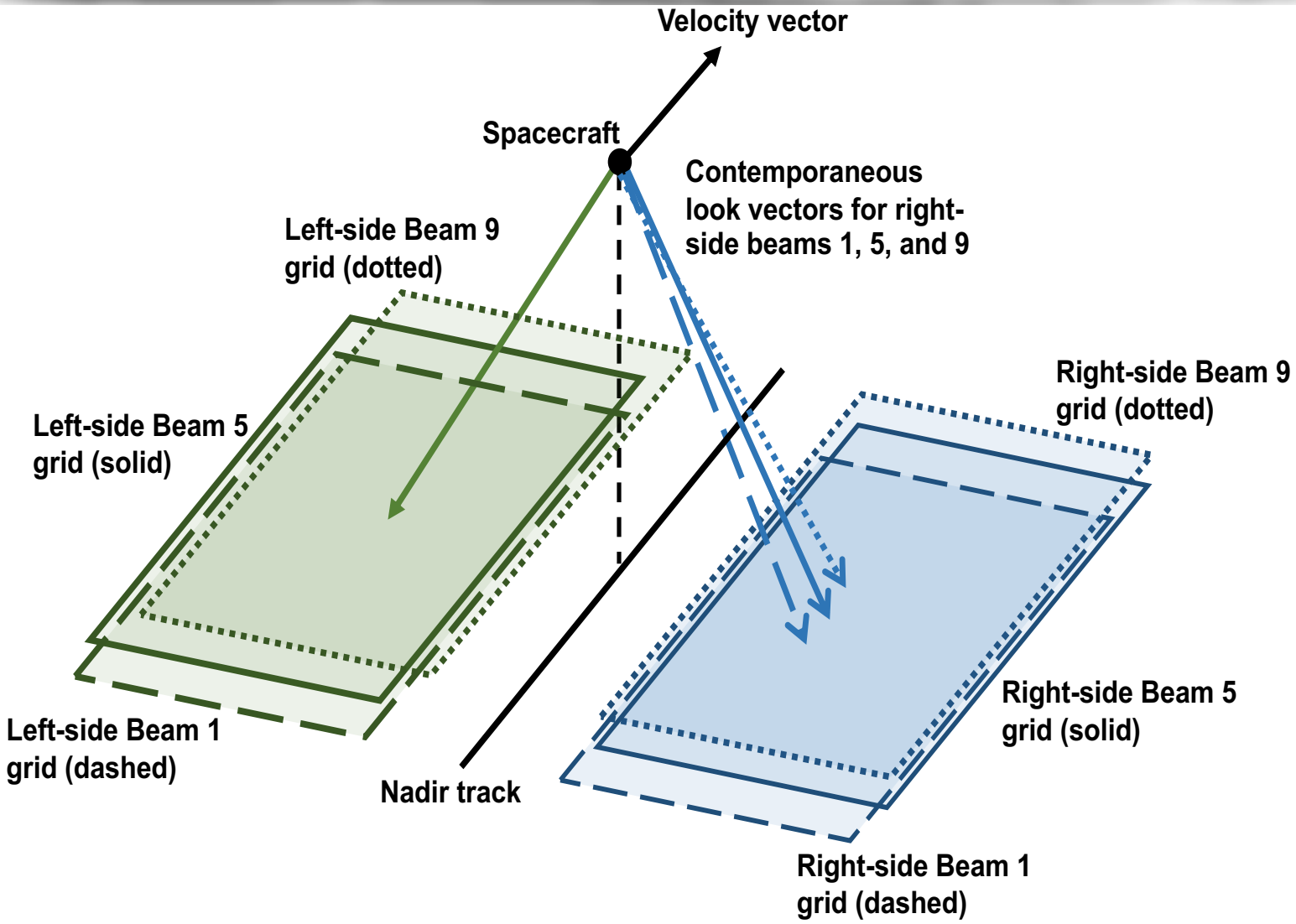
KaRIn Low Rate and High Rate Data

- Data from the KaRIn instrument downloaded in two modes: Low rate (LR) and High Rate (HR):
  - LR data available globally.
    - **Products from LR data targeted to ocean science.**
  - HR data available over only a portion of the globe.
    - Mostly collected over continents.
      - Some ocean targets (e.g., cal/val).
    - Consistent with the available data downlink capabilities.
      - Defined by configurable “HR Mask”.
      - Science Team provides inputs into definition of HR Mask.
    - **Products from HR data targeted to hydrology science.**



HR Mask circa 2015
(work in progress)

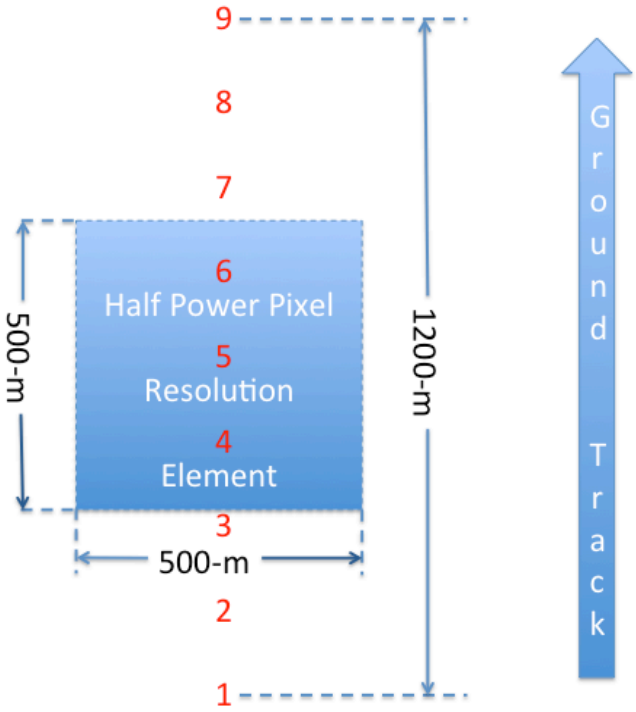
Low Rate Measurement Geometry



- KaRIn on-board LR processing forms 9 beams on each side of nadir from 10-60 km in cross track (not all beams are shown in the illustration above).
- Each beam measures the water height on the surface at ~500 m resolution
- Beam measurements are combined in ground processing to reduce noise.

Level 1B LR Interferogram Product Overview

- Provides for each of 9 Doppler beams:
  - Interferograms (INTF) after ground correction of biases introduced by limitations of on-board processing.
  - Calibrated estimates of normalized radar cross section (NRCS or sigma0).
  - Volumetric coherence.
  - Uncertainty estimates of measured quantities.
  - Spacecraft ephemeris and attitude information.
- Data from each beam is a 2-D image.
  - Each image has spatial posting of ~250 m in cross-track and along-track directions, and ~500 m resolution.
    - Filter in onboard processor has half-power width of 500x500 m.
- Beam measurements are not geolocated
- Very high volume compared to L2 LR product: 42 GB/file.
- Half-orbit (pass) files.
- NetCDF-4 format



Spatial arrangement of beams
(There is a large overlap between consecutive measurements of the same beam.)

Level 2 LR Product: Processing Approach

L1B

Beams 1-9 (250/500 m) are:

1. Height reconstructed
2. Interpolated to native grid of center beam
3. Beam combined

Unsmoothed

Unsmoothed Data is:

1. Interpolated to fixed grid
2. Averaged down to 2 km
3. SSHA generated using geophysical models

Basic

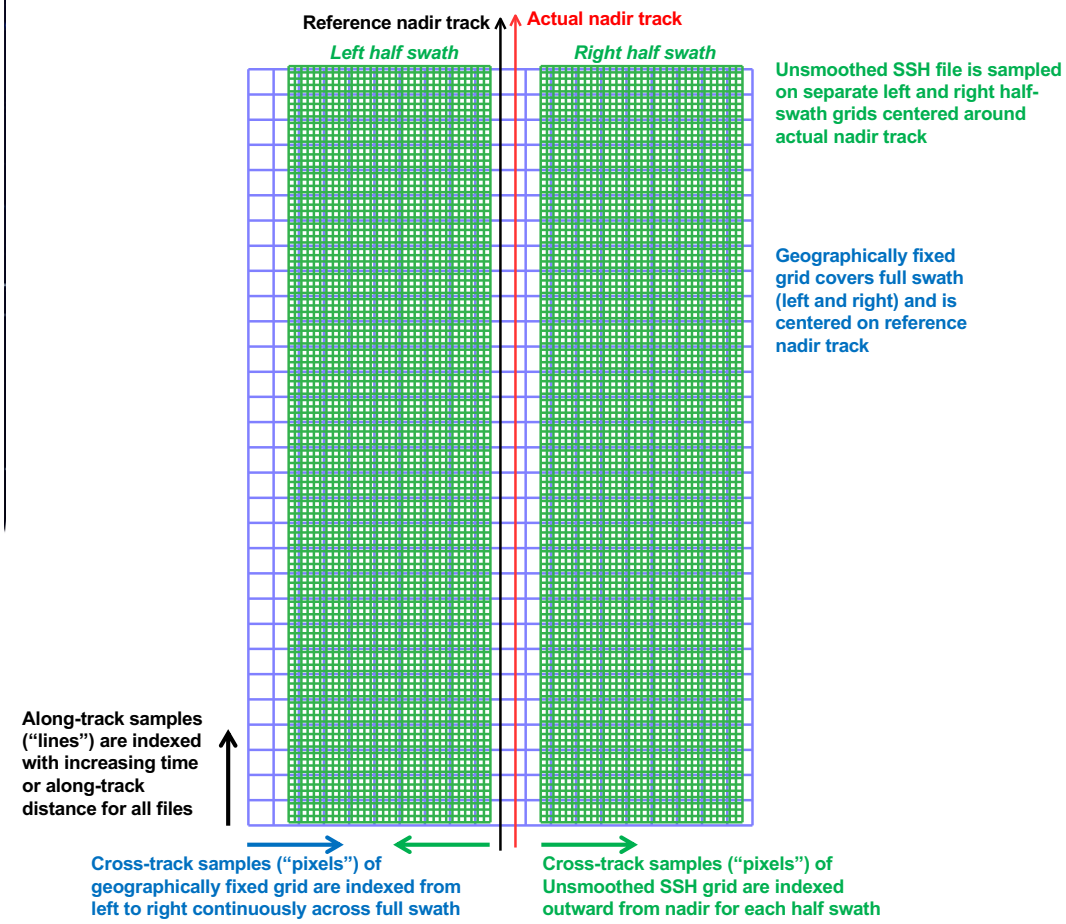
Wind and Wave

Expert

KaRIn Level 2 Low Rate (Oceans) Product Consists of Four Half-Orbit, Netcdf-4 Files

File	Name	Description
1	Basic SSH ['Basic']	• Aimed towards users of KaRIn SSH/SSHA measurements as provided. • Corrected sea surface height (SSH), sea surface height anomaly (SSHA), flags to indicate data quality, geophysical reference fields, and the crossover height correction on a 2 km geographically fixed grid. • Low volume (< 40 MB/pass) files with limited content for ease of use.
2	Wind and Wave ['WindWave']	• Aimed towards users of wind and wave measurements. • Provides measured significant wave height (SWH), normalized radar cross section (NRCS or backscatter cross section or sigma0), wind speed derived from sigma0 and SWH, model information on wind and waves, and quality flags on a 2 km geographically fixed grid. • Low volume (< 40 MB/pass) file with limited content for ease of use.
3	Expert SSH with Wind and Wave ['Expert']	• Aimed towards users interested in source of KaRIn measurements, media delays, models, and other details. • Includes copies of the Basic and the Wind and Wave files plus more detailed information on instrument and environmental corrections, radiometer data, and geophysical models on a 2 km geographically fixed grid. • High volume (~120 MB/pass) file with detailed content.
4	Unsmoothed SSH ['Unsmoothed']	• Aimed towards users interested in measurements at native posting/resolution (=250/500 m) of On-Board Processor. • Provides sea surface height (SSH), sigma0, and "mitigation" power without additional smoothing relative to the native KaRIn downlink resolution on a ~250 m native (center-beam) grid. • Very high volume (~1500 MB/pass)

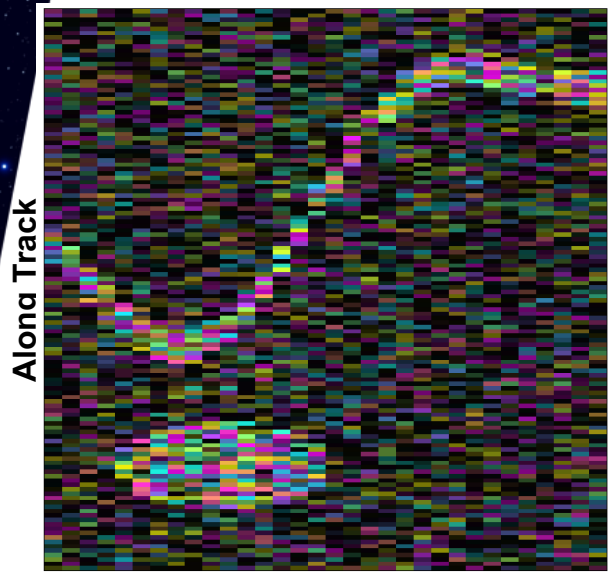
Spatial Sampling of Level 2 Low Rate Products



- Basic, Wind and Wave, and Expert files use 2 km geographically fixed grid.
  - Samples are 2 km apart in along-track and cross-track direction.
  - SWOT ground track is required to repeat to within +/-1 km from cycle to cycle.
    - Extra bins on edges accommodate +/-1 km deviations.
- Unsmoothed file provides SSH on "native" 250x250 m grid (500 m resolution).
  - Unsmoothed file best preserves horizontal resolution (but is noisier)
  - Native grid is location of center beam measurements.
  - All other beams are interpolated to center beam grid before beam combining to a single measurement per grid sample.
- LR products are provided globally.

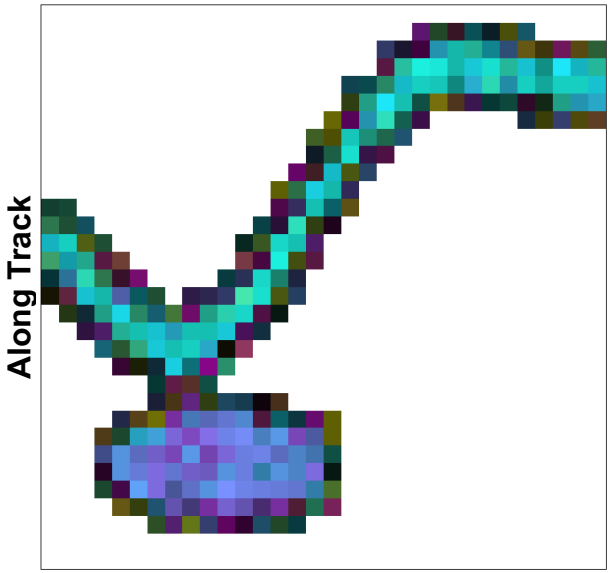
High Rate Data Product Illustration

Level 1B Single Look Complex (SLC) Product



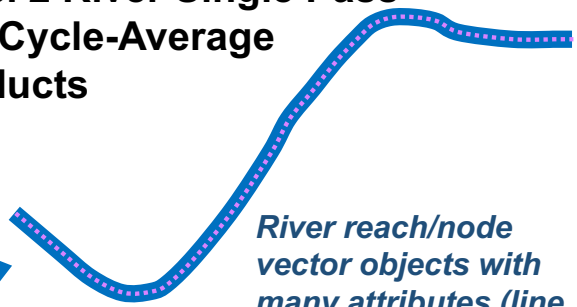
Pair of complex radar images

Level 2 Pixel Cloud (PIXC) Product



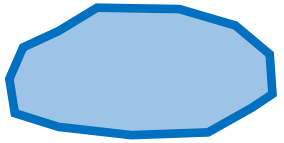
Sparse array or cloud of geolocated points in 3-D space with many pieces of information per point

Level 2 River Single Pass and Cycle-Average Products



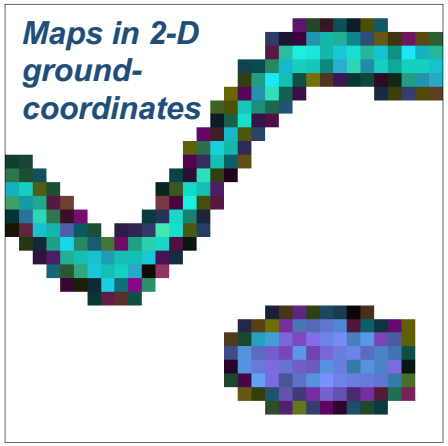
River reach/node vector objects with many attributes (line feature per reach)

Level 2 Lake Single Pass and Cycle-Average Products



Lake vector objects with many attributes (polygon feature per lake)

Level 2 Raster Product



Caution: This cartoon is highly simplified and omits many details. For conceptual introduction only.

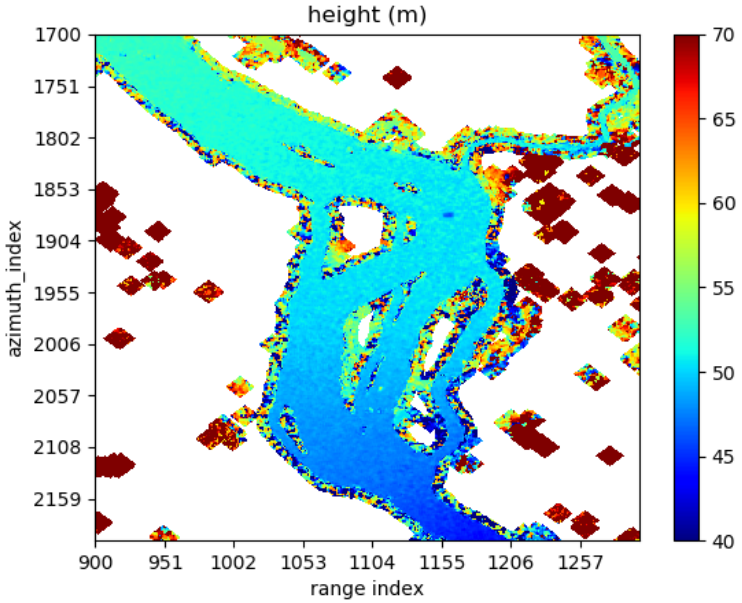
Level 1B High Rate Single-Look Complex (SLC) Product

- SLC product is intended for users with very specific needs and expertise in interferometric SAR processing.
  - **L1B SLC data are *not* geolocated**
- SLC product contains:
  - SLC images: Focused synthetic aperture radar (SAR) images from each of the two KaRIn antennas
    - *Single-look*: Images are focused to full intrinsic resolution of SWOT HR downlink data (no "multilooking" or spatial averaging has been applied yet)
    - *Complex*: Each image pixel has real and imaginary components (ie, magnitude and phase information)
  - Radiometric calibration (X factor) and noise estimates information
  - Ancillary information, e.g., platform ephemeris, attitude, and related information to describe imaging geometry, moderate resolution DEM used in processing.
- NetCDF-4 format
- Each file represents 64 x 72 km tile.

Level 2 High Rate Pixel Cloud (PIXC) Product

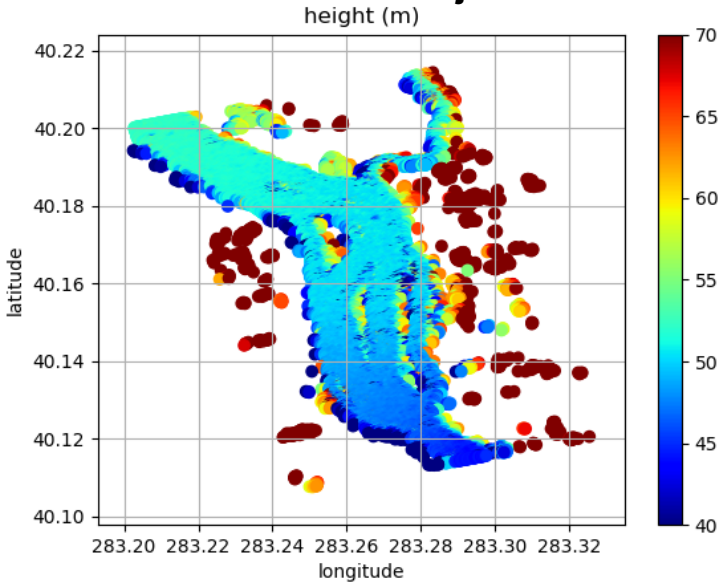
- PIXC and PIXCVec are expert products aimed towards:
  - Users interested in studying fine-scale details in a local region.
    - Finer spatial resolution, but noisier than river/lake vector and raster products.
    - **Raster product recommended for most users who need finer scale measurements than vector product.**
  - Expert users who want to use their own customized algorithms for height reconstruction and geolocation
- Most land pixels are discarded (focus on keeping water pixels)

Slant Plane Projection



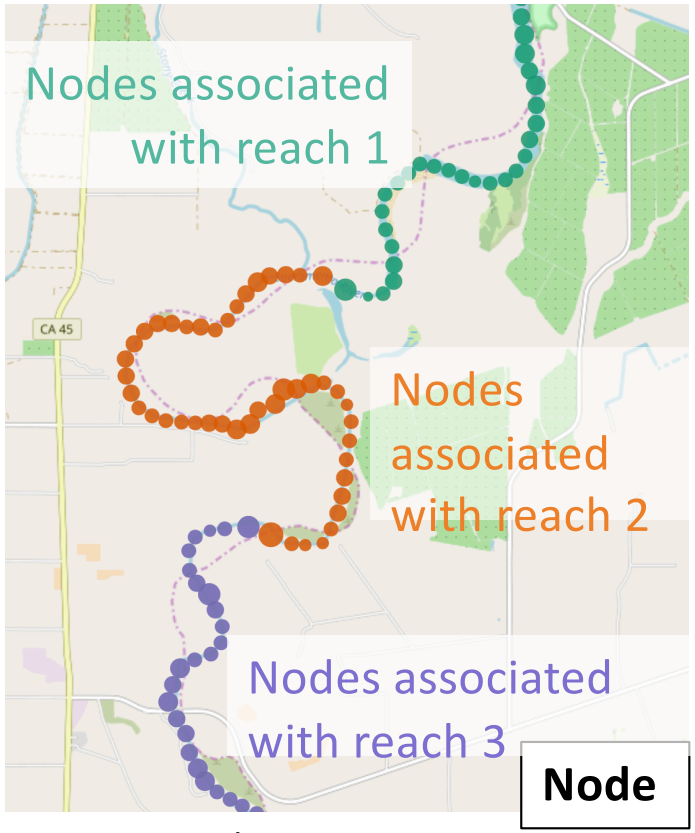
- Can be viewed either as a sparse 2-D slant-plane image or as 3-D geolocated point cloud for each pixel cloud variable.
- NetCDF-4 file format
- Each file represents 64x64 km tile

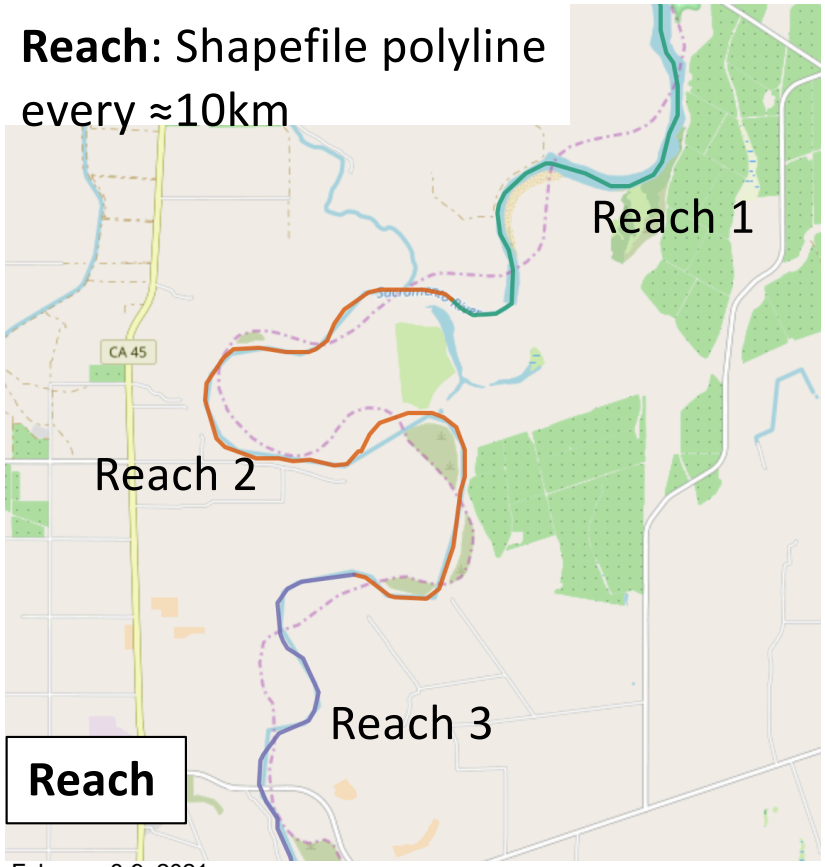
Ground Plane Projection



Level 2 High Rate River Vector Products

- **Targeted towards most hydrological science applications.**
- Provides water surface elevation, width, slope, discharge.
- ESRI shapefiles consisting of objects defined by prior river database:
  - Nodes (Shape = point) approximately every 200 m (WSE, area).
  - Reaches (Shape = polyline) ~10 km long (WSE, slope, area, discharge).
- Files represent (continent) single-pass and (basin) cycle-average products.

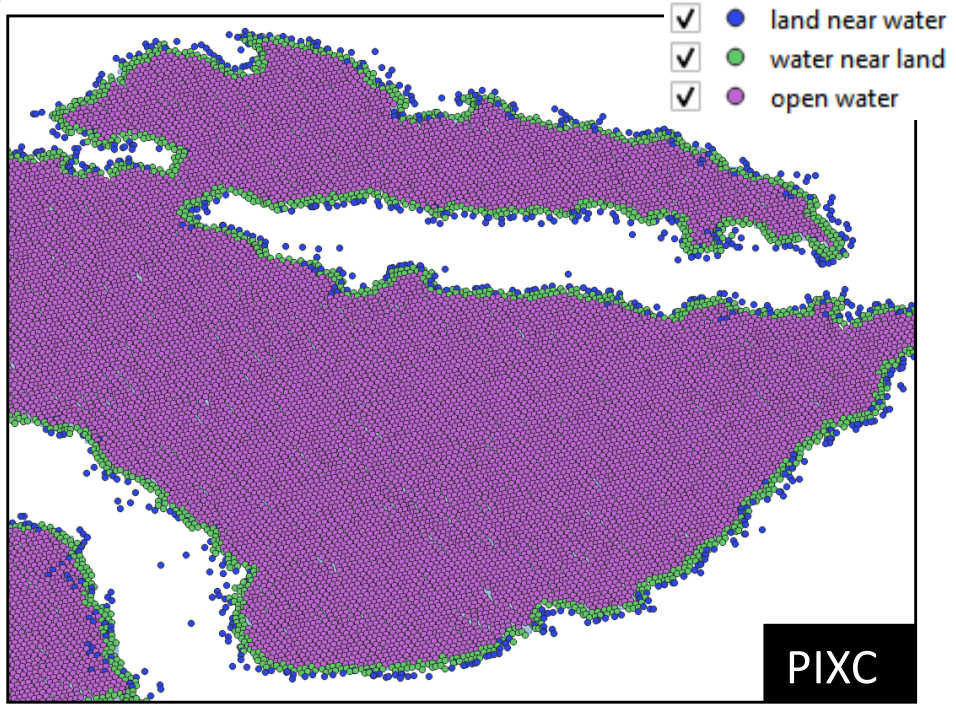


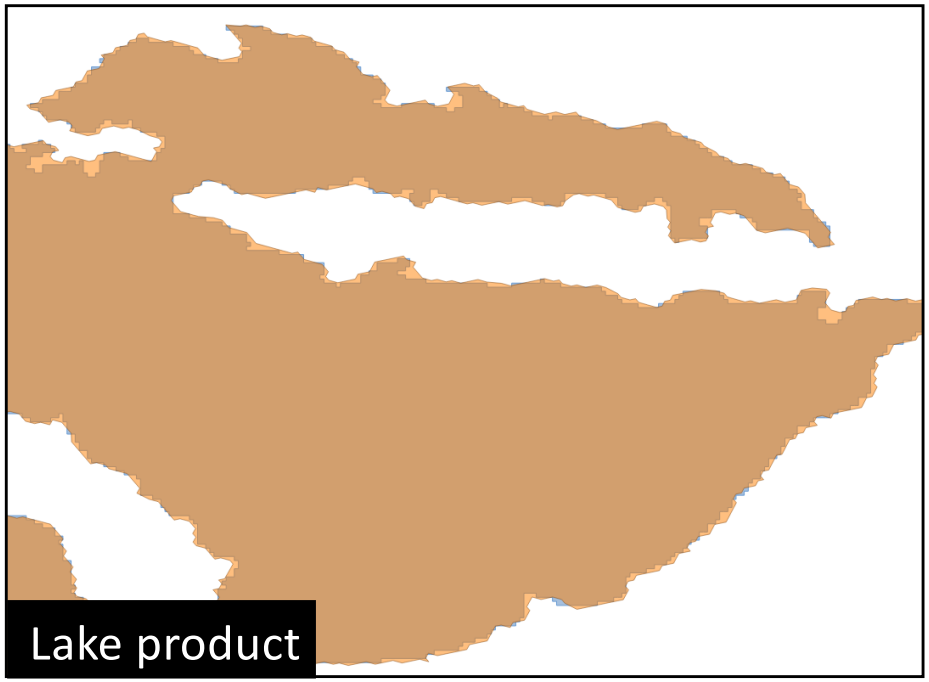


Figures courtesy Mark Hagemann, OSU

Level 2 High Rate Lake Vector Products

- **Targeted towards most hydrological science applications.**
- Provides, water surface elevation, area, storage change.
- ESRI shapefiles consisting of:
  - Object = Detected water body not attributed to rivers, i.e., lake/reservoir in prior river database (possibly observed partially), and unknown water bodies.
  - Shape = Polygon delineating lake boundary and inner island boundaries.
- Files represent single (continent) pass, and (basin) cycle-average.



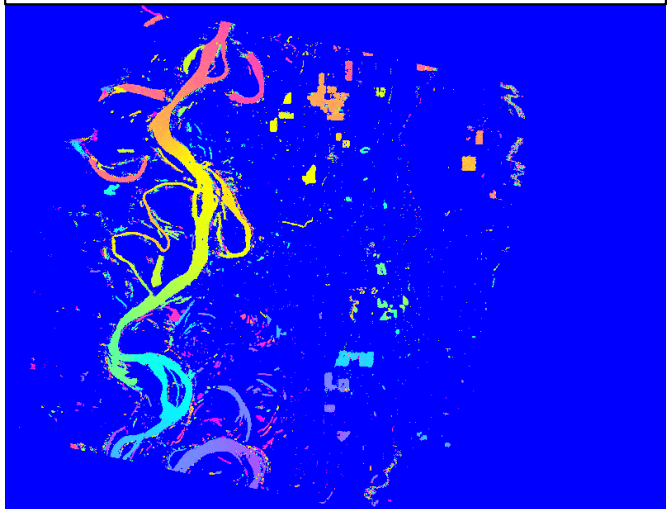


(Credits: University of Sherbrooke)

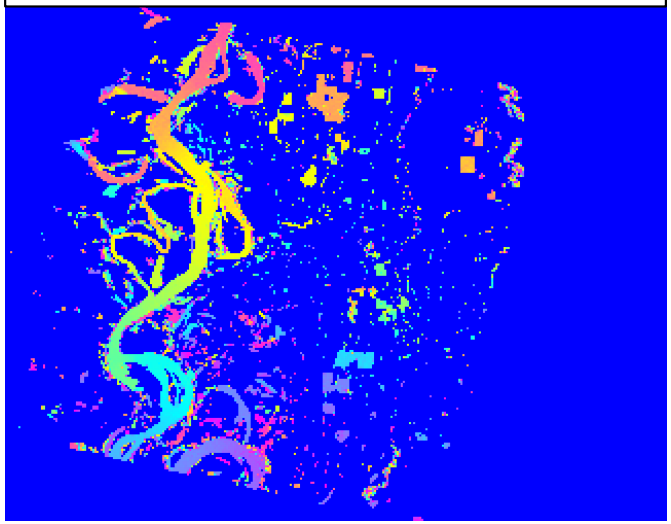
Level 2 High Rate Raster Product

- **Recommended product for users interested in fine scales.**
- Aggregates pixel cloud measurements to coarser but uniform resolution and sampling with less measurement noise.
  - Provides water surface elevation and water area.
  - Coordinate System: **UTM**
  - Resolutions: **100 m and 250 m**
  - Grid: **Geographically fixed grid**.
  - Files represent **128km x 128km** non-overlapping scene (2 x 2 set of Pixel Cloud tiles)
  - File Format: **NetCDF-4** with all rasterized layers.
- On-demand product will also be available from JPL and CNES data distribution centers.
  - Allows variety of spatial resolutions, UTM or lat/lon grids, netCDF or GeoTIFF file formats.

100m Raster – 2367/497L – 10m height wrap

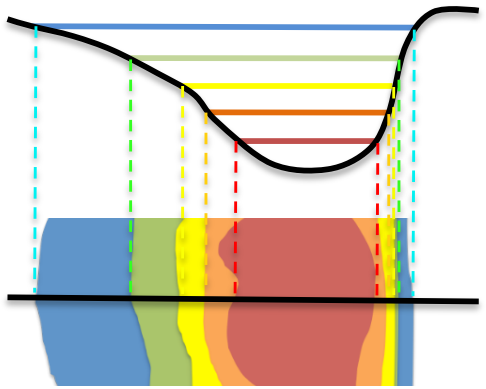


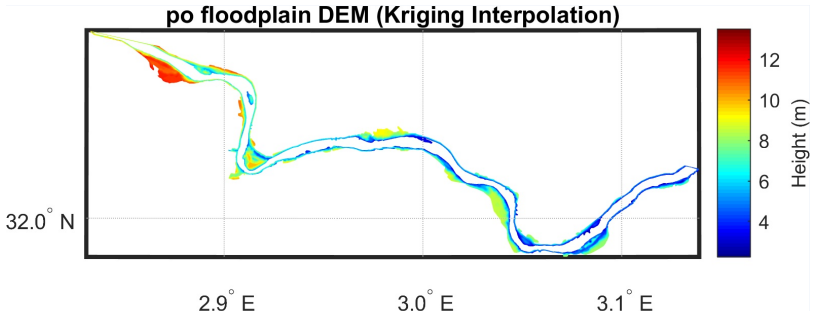
250m Raster – 2367/497L – 10m height wrap

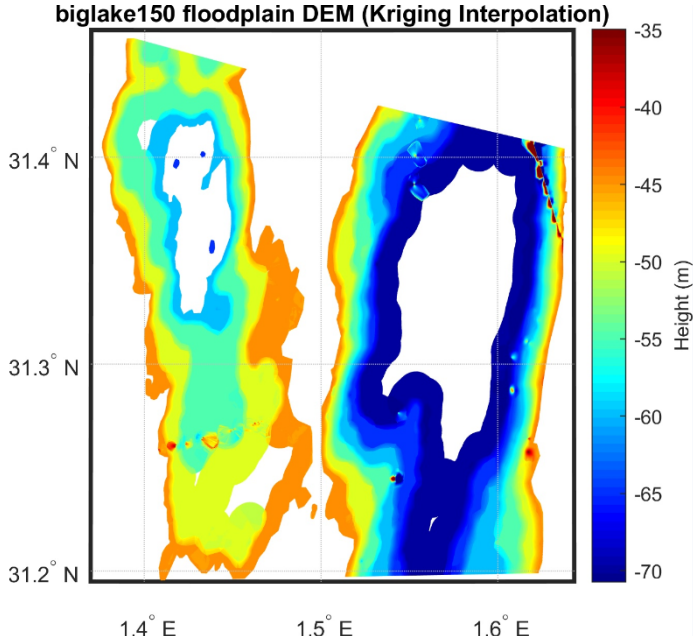


Level 2 High Rate Floodplain DEM Product

- Partial bathymetry derived from SWOT HR data
  - At least one year of data needed
  - Between observed min and max water level only
- Based on “bathtub ring” approach
  - For each date, the edge pixels of a detected water body form an (iso-)elevation curve
- Raster format (fixed geographic grid)
  - Coordinate system: UTM
  - Resolution: 50-100 m (TBC)
  - Files represent 1° x 1° scene (TBC)







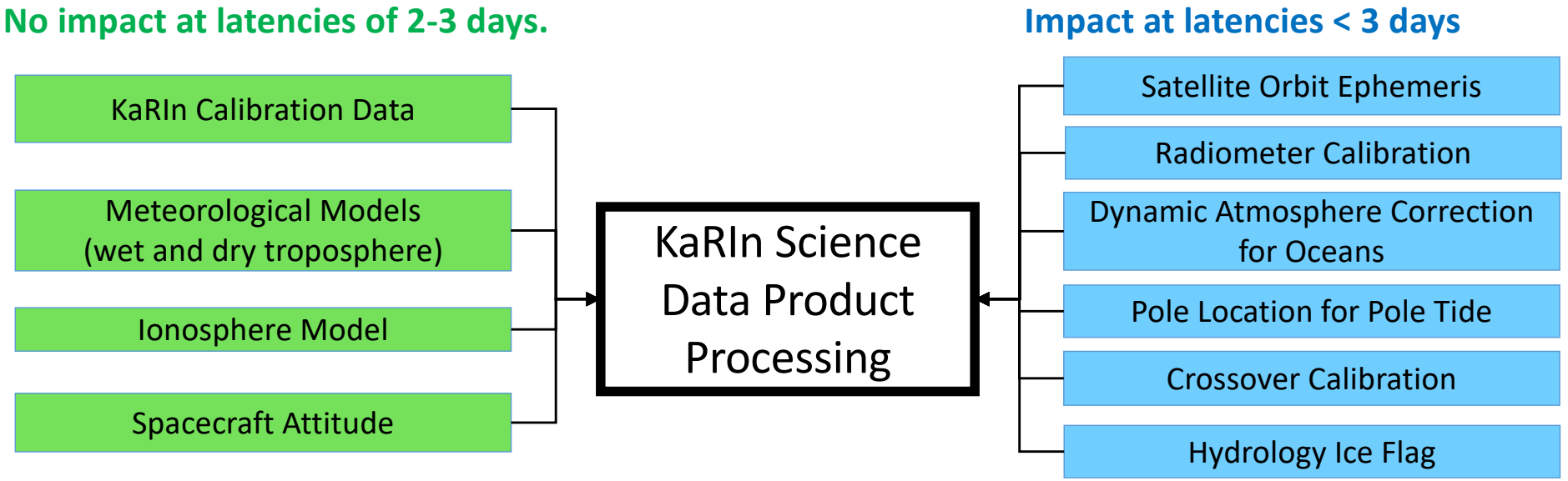
KaRIn High-Rate (Hydrology) Science Products

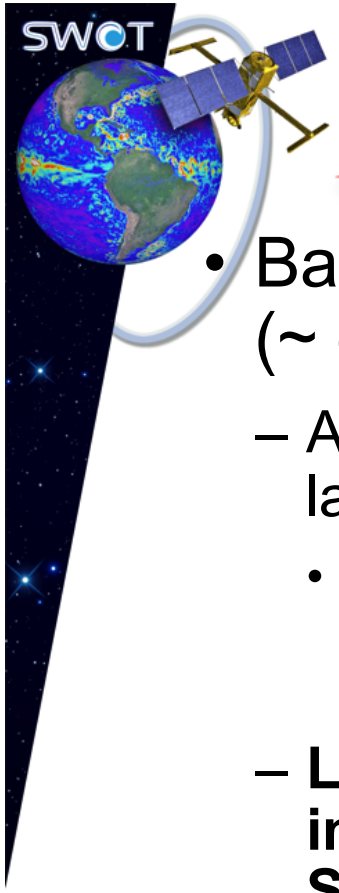
Product	Description
L1B_HR_SLC	Level 1B single-look-complex (SLC) data product with SLC images, calibration information, time-varying platform and radar system parameters, and coarse reference digital elevation model.
L2_HR_PIXC	Level 2 pixel cloud data product from SLC product with reconstructed height, water detection, flagging.
L2_HR_RiverSP L2_HR_RiverAvg*	Level 2 river data products from pixel cloud data and provides center-line locations, widths, heights, slopes, discharge, and flags for sub-reaches and total reach. _SP product extends over single pass over continent. _AVG product aggregates over one basin (or region) within one repeat cycle.
L2_HR_LakeSP L2_HR_LakeAvg*	Level 2 lake data products pixel cloud data and provides height, geolocation, area, storage change, and shape. _SP product extends over single pass over continent. _AVG product aggregates over one basin (or region) within one repeat cycle.
L2_HR_Raster	Level 2 raster product from pixel cloud data product by resampling single-pass data onto a 2-D fixed grid, with water surface elevation and inundation extent (area and fraction).
L2_HR_FPDEM	Level 2 Flood Plain Digital Elevation Map providing height and quality flag in raster format derived from multiple cycles of SWOT acquisitions. Resolution of 50-100 m (TBC).

* RiverAvg and LakeAvg products are generated only during nominal 21-day science orbit.

SWOT KaRIn Routine Products

- Generate routine (forward processing) KaRIN science data products with latency goal of < 3 days.
  - Use preliminary inputs for some auxiliary data inputs:
    - Orbit ephemeris, radiometer calibration, dynamic atmospheric correction model, Earth pole location, crossover calibration, hydrology climatology ice flag.
  - Expected to meet project requirements based upon current best estimates.
    - **Hydrology height error from 5.4 to 5.7 cm.**
    - **No change to hydrology slope error.**
    - **Negligible impact to sea surface height spectrum requirements.**
  - Project maintains requirement for 45-day latency.





SWOT KaRIn Reprocessed Products

- Baseline includes enhanced reprocessing plan (~ once/year):
  - Achieve best accuracy that was originally intended from 45-day latency.
    - Use precise orbit determination, calibrated radiometer data, crossover calibration, model for dynamic atmosphere correction, Earth pole location, include hydrology ice flag based upon optical imagery.
  - **Leverage expected evolution of science data algorithms when in-flight data become available, and use updated (based upon SWOT measurements) hydrology databases.**
    - KaRIn instrument processing algorithms are certain to evolve when first-of-its-kind in-flight data become available.
  - Forward processing transitions to algorithms used in reprocessing.
    - Facilitates self-consistent time series across life of mission.

User Documents

User Handbook

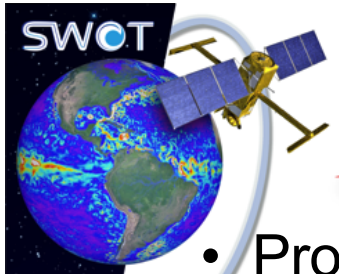
- **Recommended for ALL users.**
- Mission Overview, Terminology and Definitions
- Mission Design and Payload
- Basic Measurement Principles of Payload
- Radar phenomenology
- Geophysical contributors to measurements
  - E.g., media delays, MSS, tides, etc.
- Processing flow

Product Description Documents

- **Recommended for general use of individual products.**
- Separate document for each science data product
- Product-specific content
- Structure
- Qualitative description
- Detailed format and content
- Size and latency

Algorithm Theoretical Basis Documents

- **Targeted to expert users interested in details of how reported variables are computed.**
- Separate document for each science data product
- Physical and mathematical basis of algorithms.
- Describes how variables in products are computed.
- Qualitative description of input and output data



Summary and Status

- Product definitions are mature for most products.
  - Detailed product description documents available at: https://podaac.jpl.nasa.gov/SWOT?tab=datasets&sections=about
    - Completed review by Subject Matter Experts from the Science Team.
    - **Minor evolutions to product descriptions are expected over next 2 years.**
  - Three pending product description documents:
    - RiverAvg and LakeAvg products by mid-2021.
    - Flood Plain Digital Elevation Map (FPDEM) by end of 2021.
      - First FPDEM product after one of in-flight data available.
- Sample data products to be provided to users by March, 2021.
  - Aimed towards allowing users become accustomed to the KaRIn data product formats and data distribution interfaces.
    - **Not to be used to evaluate instrument performance or for scientific research.**
  - Distributed through PODAAC and CNES data distribution centers.
- User handbook to be generated by early 2022.
- Algorithm Theoretical Basic Documents release by early 2022.
  - Review by Subject Matter Experts from Science Team through 2021.