SWOT LR data products

(update of 2019 talk by Stiles and Steunou)

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Woods Hole Oceanographic Institution

SWOT Science Team Meeting

2022 June 27

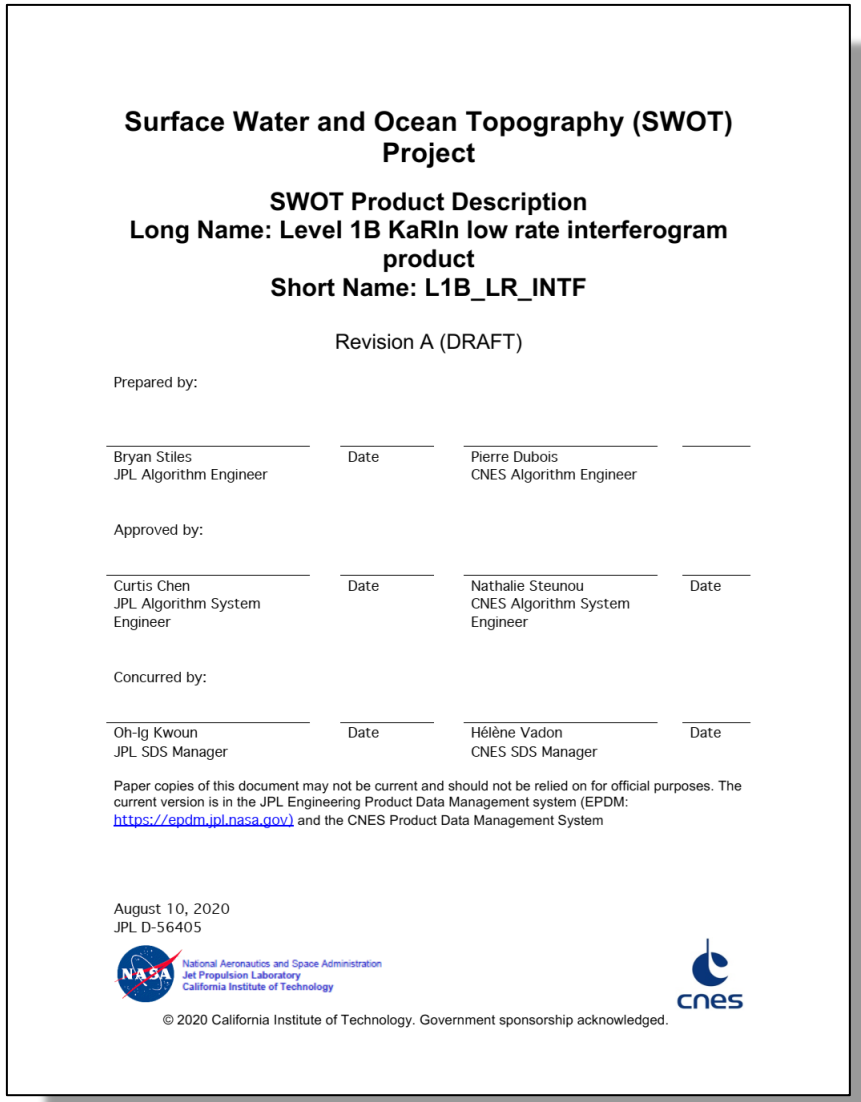
Purpose

- High-level overview of SWOT “Low-Rate” (LR) products
- Special highlights on some product properties
- Link to external resources of reference

Essential references listed in these slides

- Product Description Documents (PDD)
- Algorithm and Theoretical Basis Documents (ATBD)
- Simulated products & simulators

Definitive reference: Product Description Documents (https://podaac.jpl.nasa.gov/SWOT --> datasets)



Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name: Level 1B KaRIn low rate interferogram product
Short Name: L1B_LR_INTF

Revision A (DRAFT)

Prepared by:

Bryan Stiles JPL Algorithm Engineer	Date	Pierre Dubois CNES Algorithm Engineer	

Approved by:

Curtis Chen JPL Algorithm System Engineer	Date	Nathalie Steunou CNES Algorithm System Engineer	Date

Concurred by:

Oh-Ig Kwoun JPL SDS Manager	Date	Hélène Vadon CNES SDS Manager	Date

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August 10, 2020
JPL D-56405

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

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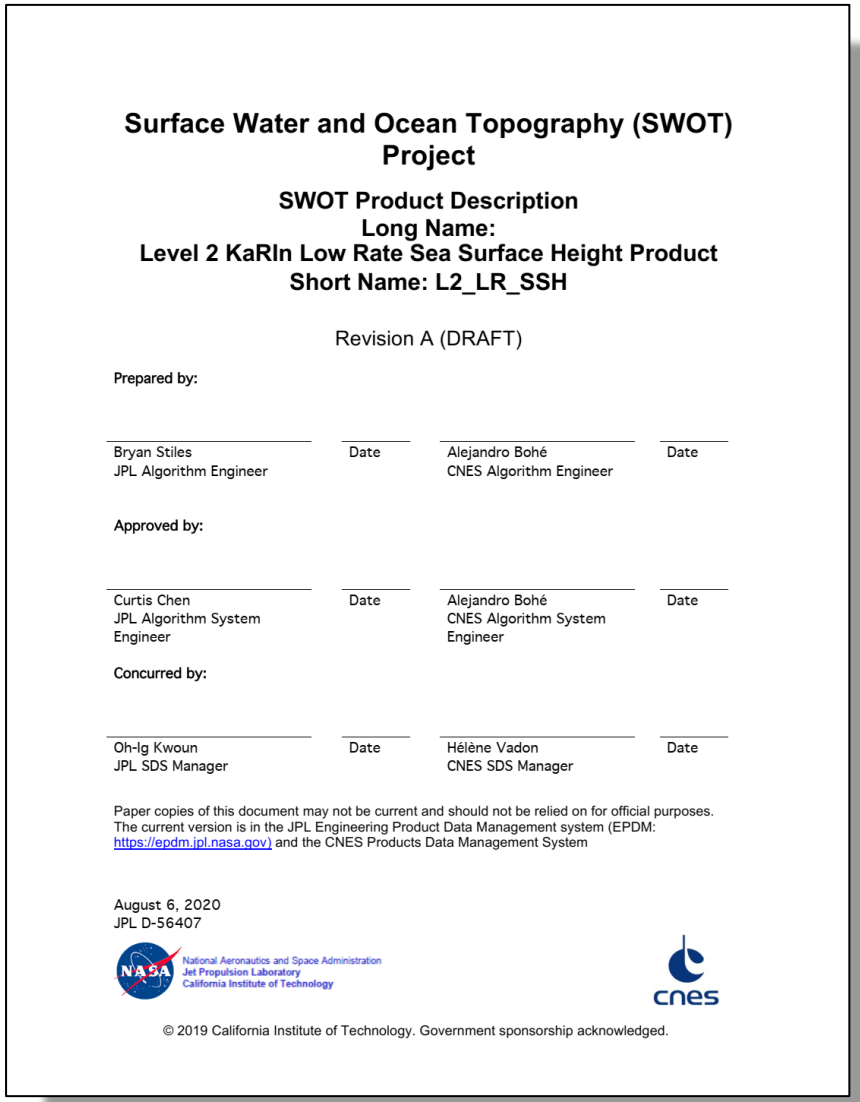

Surface Water and Ocean Topography (SWOT) Project

SWOT Product Description
Long Name:
Level 2 KaRIn Low Rate Sea Surface Height Product
Short Name: L2_LR_SSH

Revision A (DRAFT)

Prepared by:

Bryan Stiles JPL Algorithm Engineer	Date	Alejandro Bohé CNES Algorithm Engineer	Date

Approved by:

Curtis Chen JPL Algorithm System Engineer	Date	Alejandro Bohé CNES Algorithm System Engineer	Date

Concurred by:

Oh-Ig Kwoun JPL SDS Manager	Date	Hélène Vadon CNES SDS Manager	Date

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August 6, 2020
JPL D-56407

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

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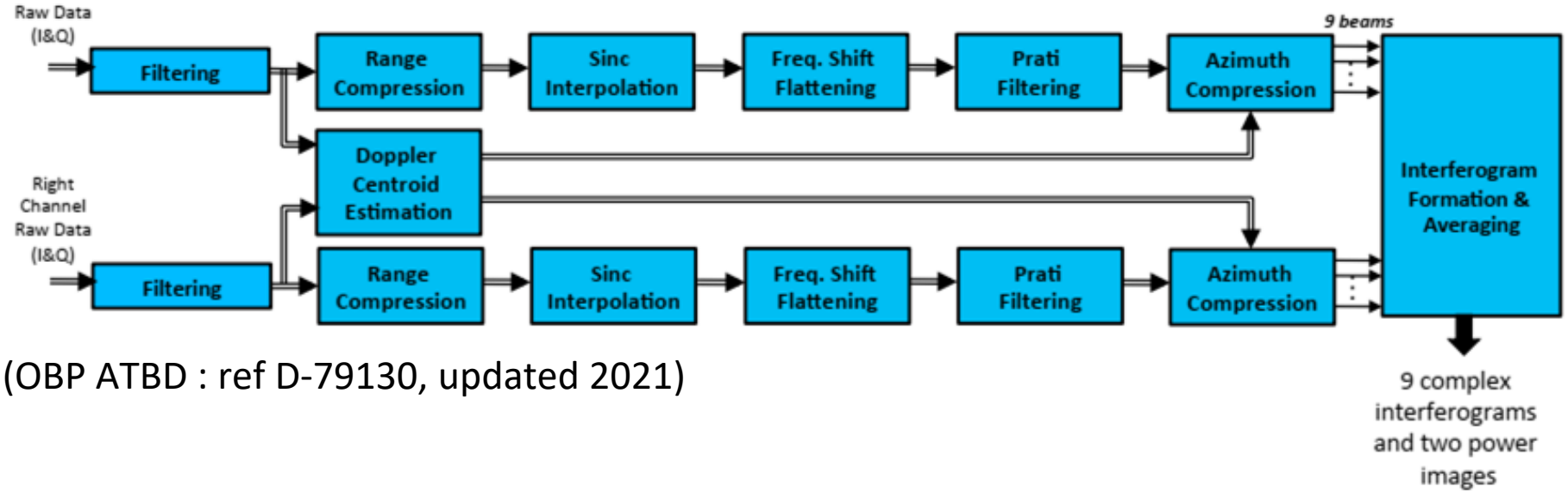
Overview of LR processors

1. The onboard processor (OBP)
   - Output : 9 beams, interferograms, power images, Doppler centroid
2. The Level-1B processor (L1B)
   - Remove instrument bias, add precise orbit determination, quality flags
   - Output: 9 beams, Interferogram, Sigma0, volumetric decorrelation, geolocation
3. The Level-2 processor (L2)
   - Convert interferograms into SSHA
   - Co-locate and combine 9 beams into one single SSH
   - Lower resolution to 2 km and apply geophysical models & references
   - Compute wind speed and H_s parameters
   - Output: SSHA, corrections, Hs, Wind speed, flags, uncertainty

In parallel and used by the above: NADIR, POD, XCAL, and RAD processors

Onboard processor (OBP): ATBD available



(OBP ATBD : ref D-79130, updated 2021)

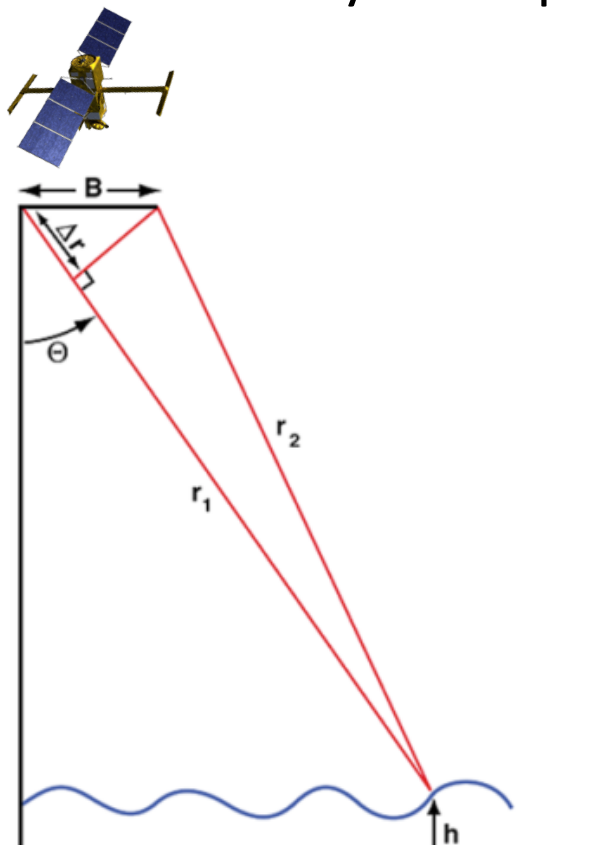
Take-home messages:

- ATBD is rich (e.g. pseudo-code) although probably of interest only for radar experts
- KaRIn is a highly directional instrument like SAR imagers (unlike more intuitive imagery)
  - Radar range ~ cross-track direction
  - Azimuth ~ along-track direction

Output: 9 beams, interferograms, radar power images, Doppler centroid

SWOT concept in 2 pictures and 2 documents

The basic interferometry concept is simple

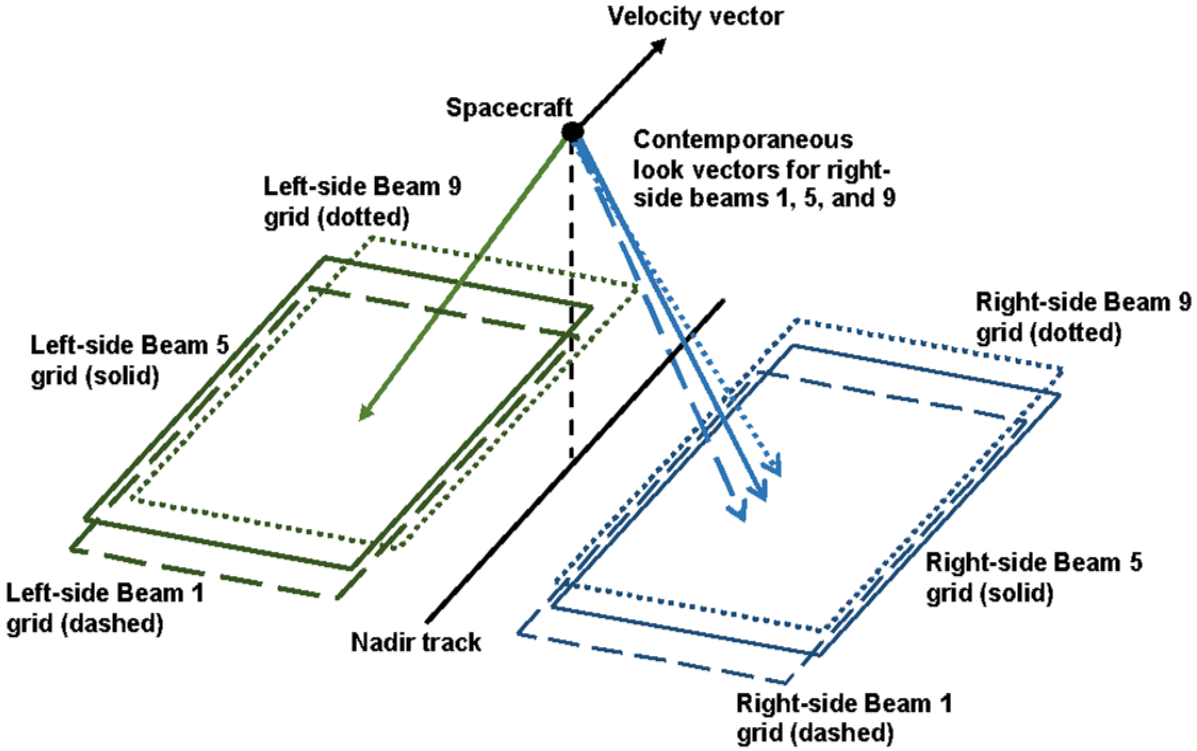


$$\varphi = 2kr_1 - k(r_1 + r_2) \approx kB\sin(\theta)$$

$$h \approx H - r_1\cos(\theta)$$

(Error budget document, JPL D-79084)

But implementation is complex
(e.g. 9 beams, SAR processing, and
multiple steps of interpolation/filtering)

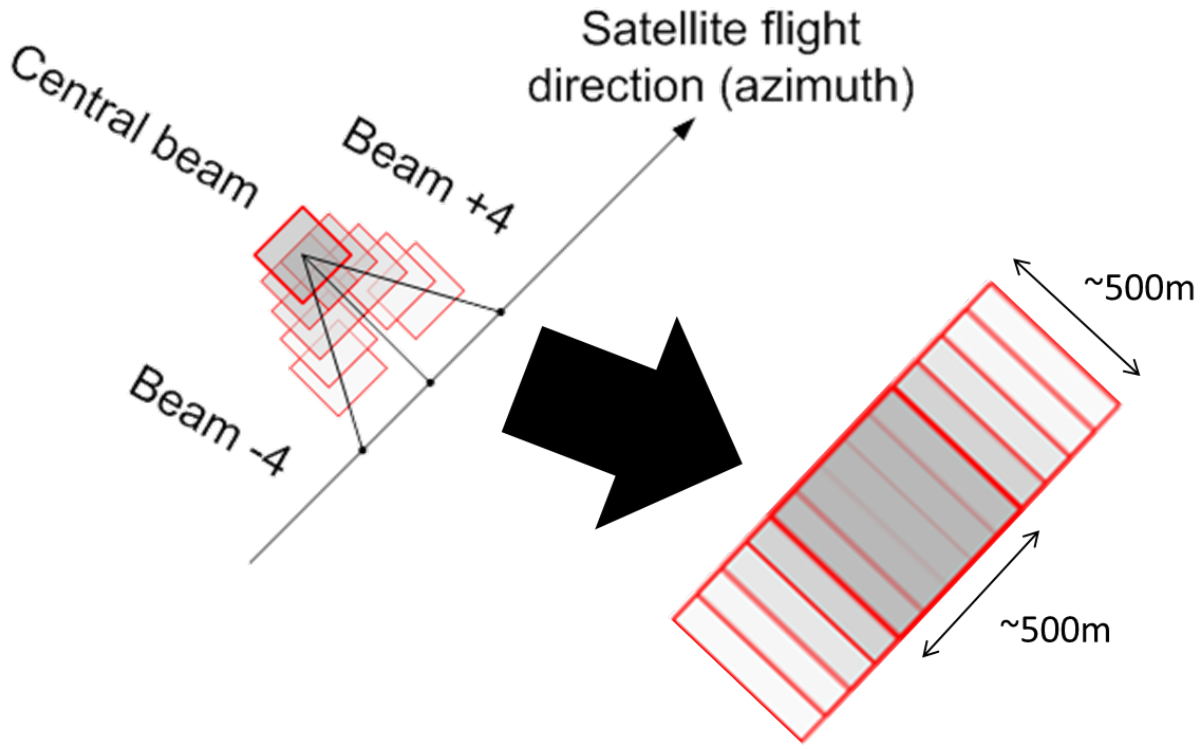


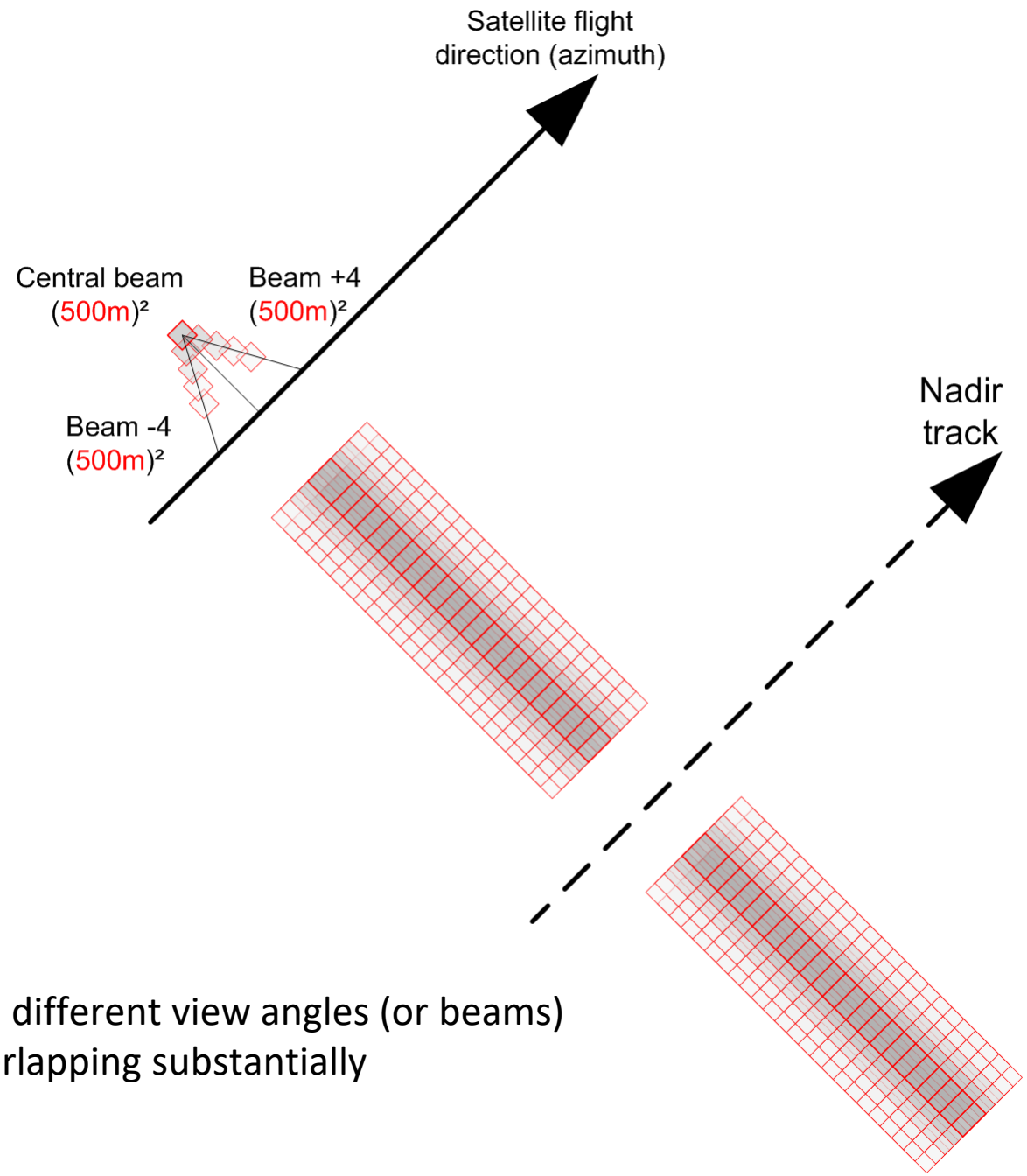
(LR L1B Product Description Document, JPL D-56405)

Highlights of onboard and ground processing

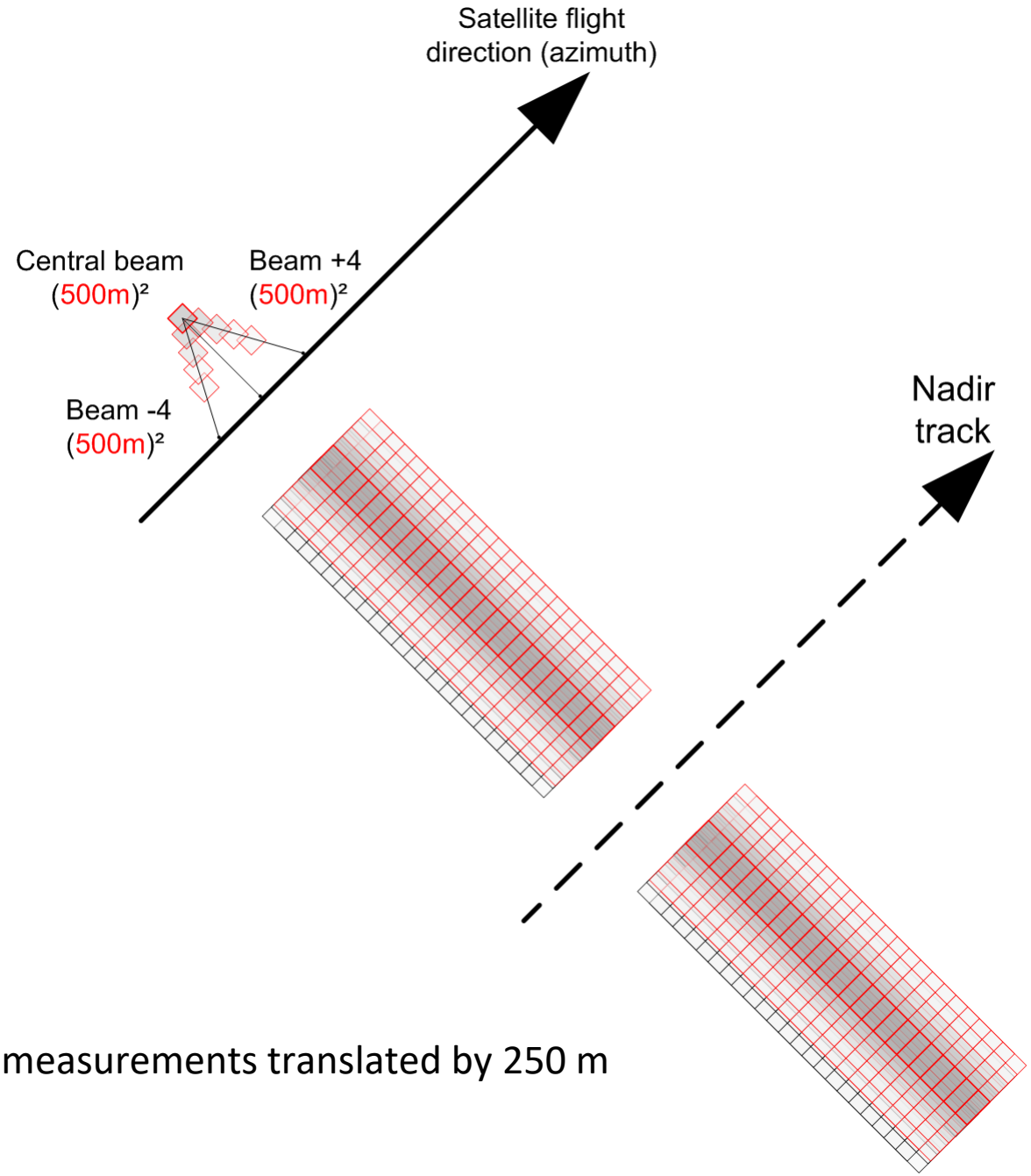
Unfocused SAR processing (Doppler beam sharpening)

From 3 km antenna footprint to 500 m synthetic footprint

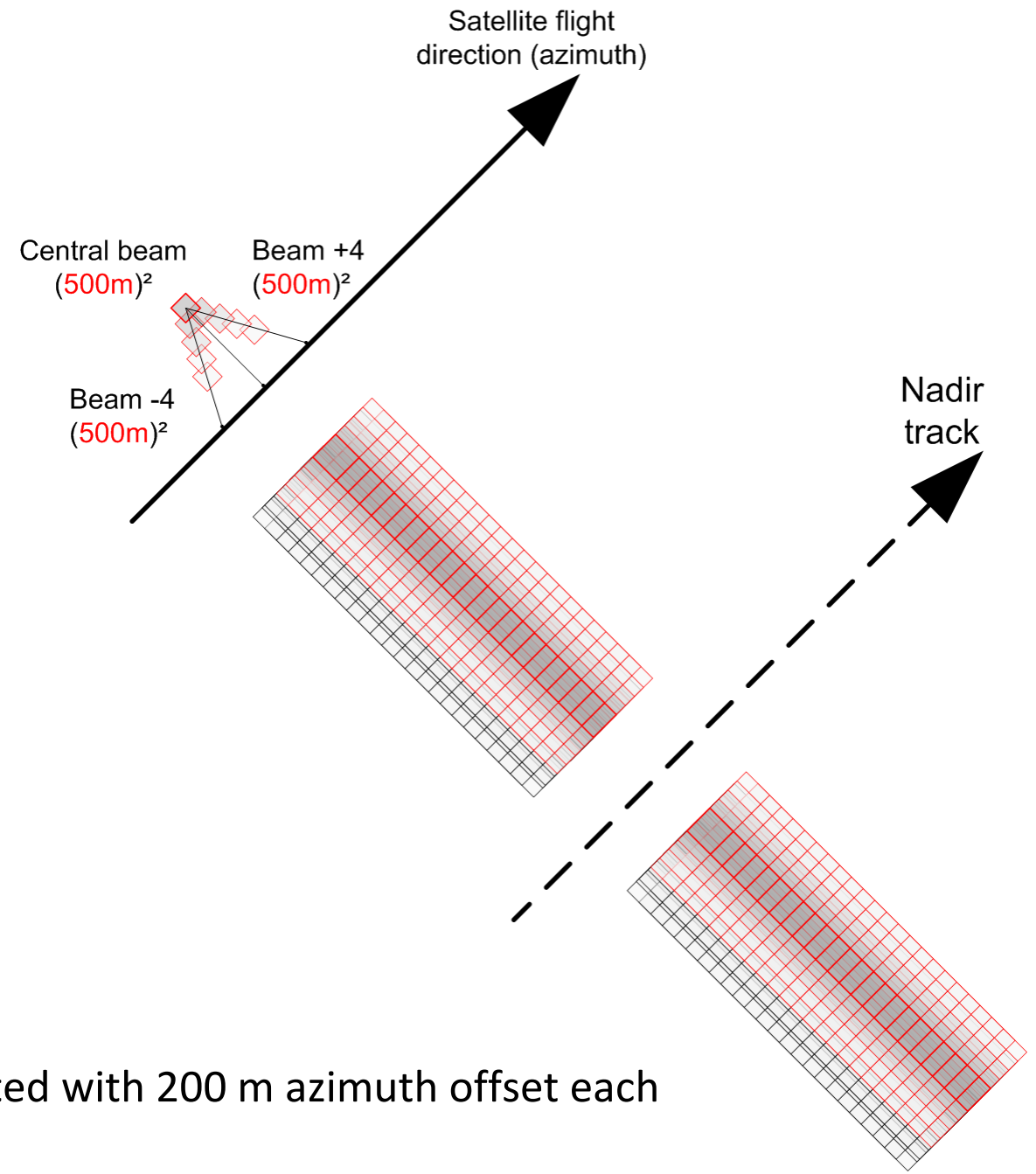




9 lines from 9 different view angles (or beams)
Pixels are overlapping substantially



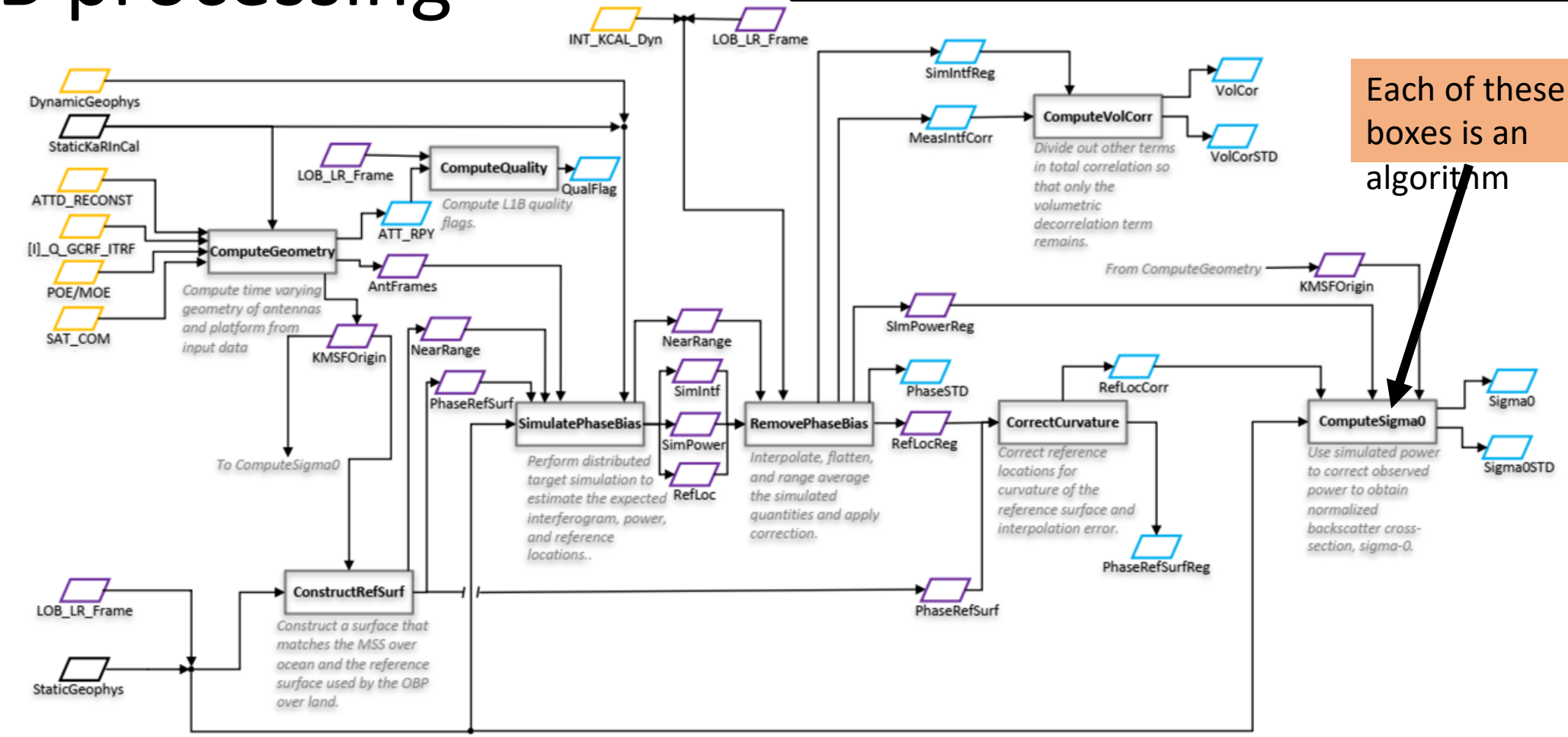
Subsequent measurements translated by 250 m



9 images collected with 200 m azimuth offset each

L1B processing

In a nutshell: remove instrument bias, convert into geophysical content, add orbit determination, add quality flags



Each of these boxes is an algorithm

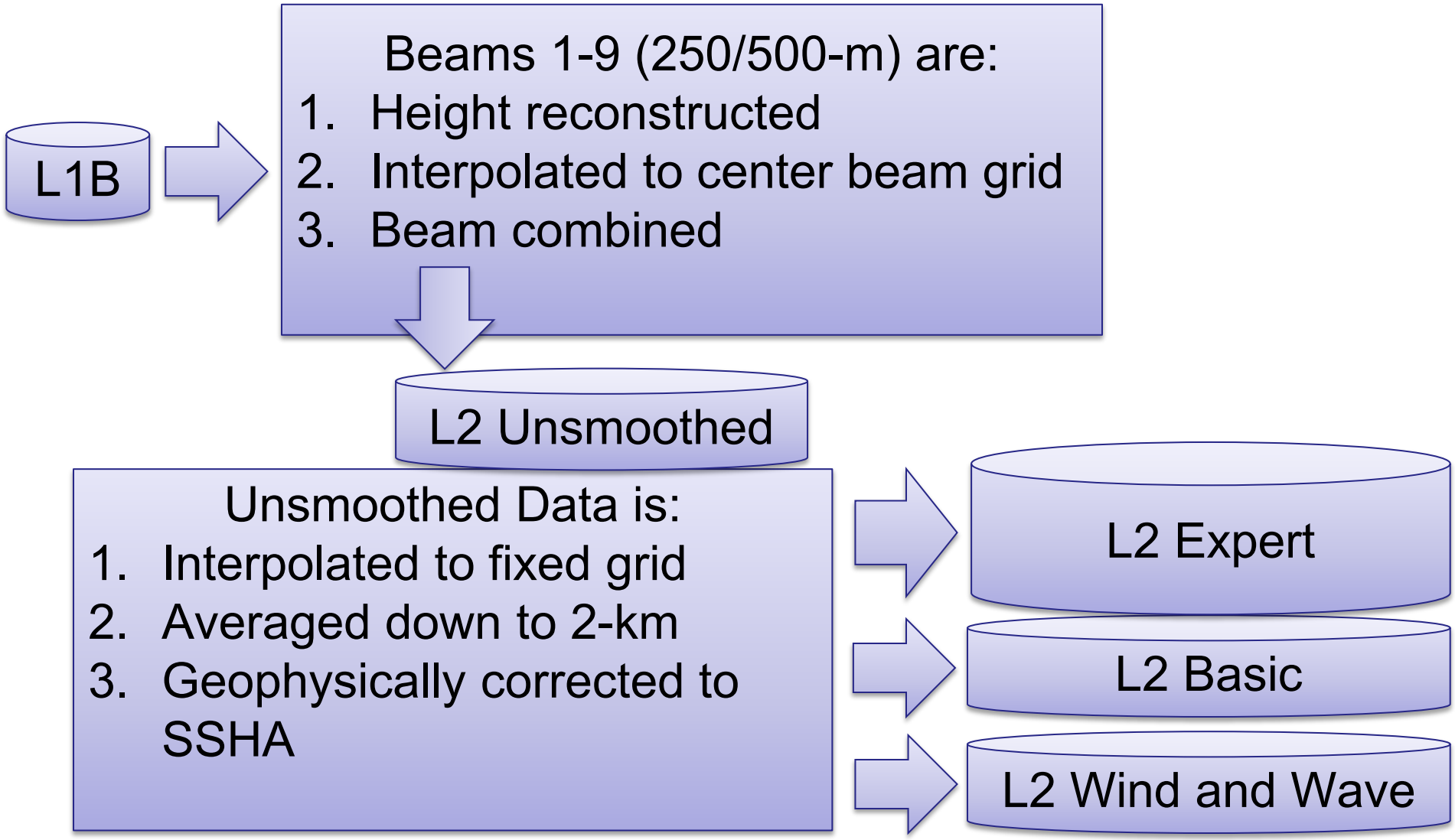
Output: 9 beams and interferograms (not SSH), Sigma0, volumetric decorrelation, geolocation

(draft L1B ATBD, ref JPL D-105501)
(PDD, ref JPL D-56405)

L1B main parameters of interest

1. Interferogram, corrected for angular phase biases
2. Interferogram reference location
3. Phase bias correction that was applied to the interferogram
4. Normalized radar cross section (sigma0)
5. Volumetric correlation
6. Uncertainty estimates for measured quantities
7. Correction terms, quality flags, and associated information
8. Spacecraft ephemeris and attitude information

From L1B to Level 2 Product: Processing Approach

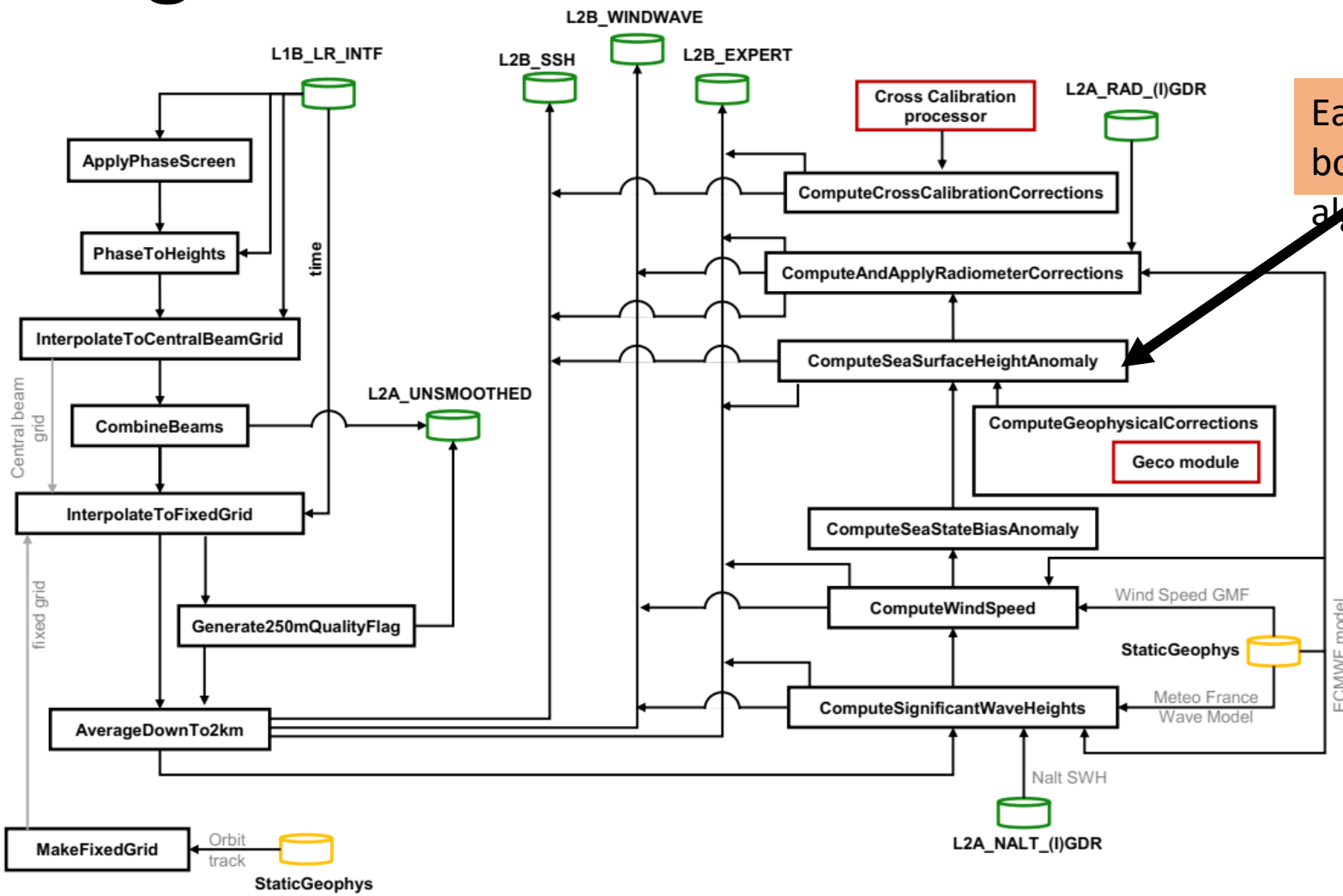


Baseline Level 2 Oceans Product Consists of 4 Half-orbit granule, Netcdf-4 files

File	Name	Description
1	Basic SSH ['Basic']	Provides 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.
2	Wind and Wave ['WindWave']	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.
3	Expert SSH with Wind and Wave ['Expert']	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.
4	Unsmoothed SSH ['Unsmoothed']	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.

L2 processing

In a nutshell: convert interferograms into SSH, combine 9 beams into one single SSH, generate 2-km product, and apply geophysical models & references



Each of these boxes is an algorithm

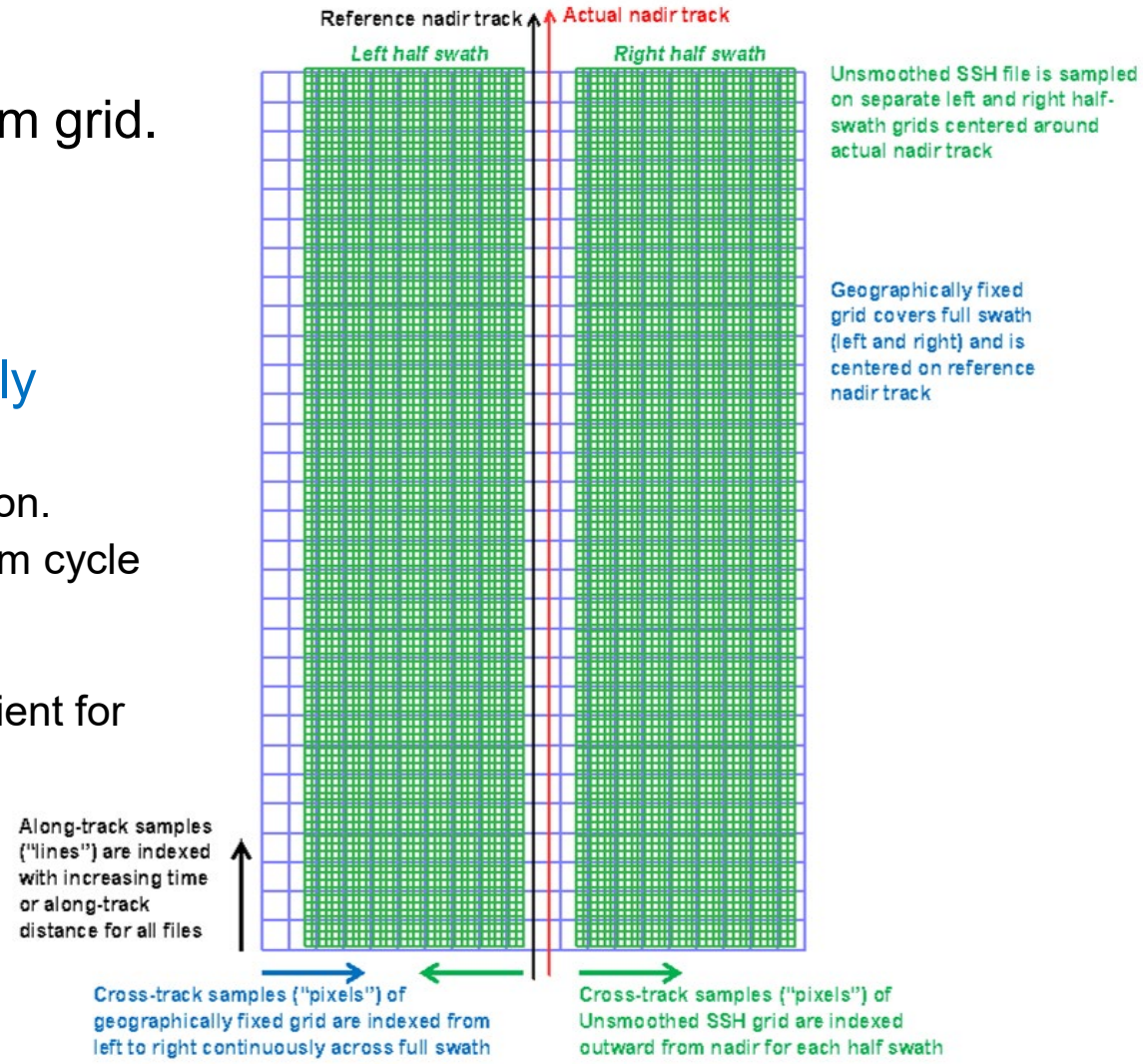
Output: SSHA, Hs, Wind speed, corrections and flags, uncertainty

(draft L2 ATBD, ref TBD)
(L2 PDD, ref D-56407 for KaRIn, ref SALP-ST-M-EA-17043-CN_0101 for nadir)

Spatial Sampling of Products

- Unsmoothed product provided on ”native” 250x250 m grid.
  - Native grid is location of center beam measurements.
  - All other beams interpolated to center beam grid.

- Basic, Wind and Wave, and Expert products use only 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 to accommodate +/-1 km deviations.
  - Geographically-fixed grid is expected to be especially convenient for most users.



L2 main parameters of interest

The L2_LR_SSH product provides:

- Sea surface height (SSH) and SSH anomaly (SSHA).
- Measured significant wave height (SWH) and normalized radar cross section (NRCS or backscatter cross section or sigma0), wind speed derived from sigma0 and SWH, and wind and wave fields from numerical weather models.
- Uncertainty estimates for all measurements.
- Flags indicating data quality and off-nominal conditions.
- Information on instrument and environmental corrections from both SWOT measurements (including the microwave radiometers) and external models.
- Additional geophysical model data that may be useful in analysis and interpretation of the data.

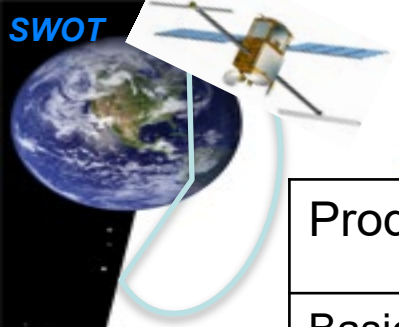
The L2_LR_SSH product does not provide SSH data from the SWOT nadir altimeter. Nadir altimeter data are available from a separate data product [3].

“Basic” SSH File

- Time and geolocation.
- Two values of sea surface height (SSH) and one value of uncertainty.
  - ssh_karin: Using wet troposphere correction from radiometer measurements.
    - Computed as ssh_karin = ssh_karin_2 + equivalent vertical (model-radiometer) wet troposphere correction difference.
    - Defaulted where radiometer measurements contaminated by rain, ice, and land.
  - ssh_karin_2: Using wet troposphere correction from ECMWF model.
    - Mitigates loss/degraded KaRIn SSH measurements due to rain, ice, and land contamination of radiometer measurements.
- Two values of sea surface height anomaly (SSHA).
  - ssha_karin and ssha_karin_2: Computed from ssh_karin and ssh_karin_2, respectively.
  - Geophysical models used to correct SSH for contributions from mean sea surface, solid Earth tide, ocean tide, load tide, pole tide, and dynamic atmosphere correction.
    - Applied values provided in “Expert” file.
- Mean sea surface (as applied to SSHA) and geoid.
- Model for coherent internal tide provided separately. Not applied to SSH/SSHA.
- Crossover height correction provided. Not applied to SSH/SSHA.
- Surface type, ice (from EUMETSAT OSI SAF), and rain flags.

"Expert" SSH with Wind and Wave File

- Aimed toward users interested in source of KaRIn measurements, media delays, models, and other details. Its content is somewhat similar to the GDR nadir products.
  - High volume (~120 MB/pass) file with detailed content.
- Content includes:
  - Exact copies of "Basic" and "Wind and Wave" files as separate NetCDF groups.
  - "Expert" NetCDF group with:
    - ♦ Nadir location.
    - ♦ Spacecraft altitude and altitude rate.
    - ♦ Spacecraft attitude information (roll, pitch, yaw, heading)
    - ♦ sigma0 calibration and corrections.
    - ♦ Radiometer brightness temperature measurements, water vapor, and liquid water.
    - ♦ Geophysical models:
      - All geophysical models are consistent with nadir altimeter product and Sentinel-6:
      - Second MSS model, two ocean/load tide models, second internal tide model, mean dynamic topography, solid Earth tide, pole tide, dynamic atmosphere correction, inverse barometer correction)
        - First MSS and internal tide models in "Basic" group.
    - ♦ Equivalent vertical media delay corrections :
      - Radiometer and model wet troposphere, model dry troposphere, model ionosphere.
    - ♦ Sea state bias with source of SWH.
    - ♦ Model-based rain rate



Data volume

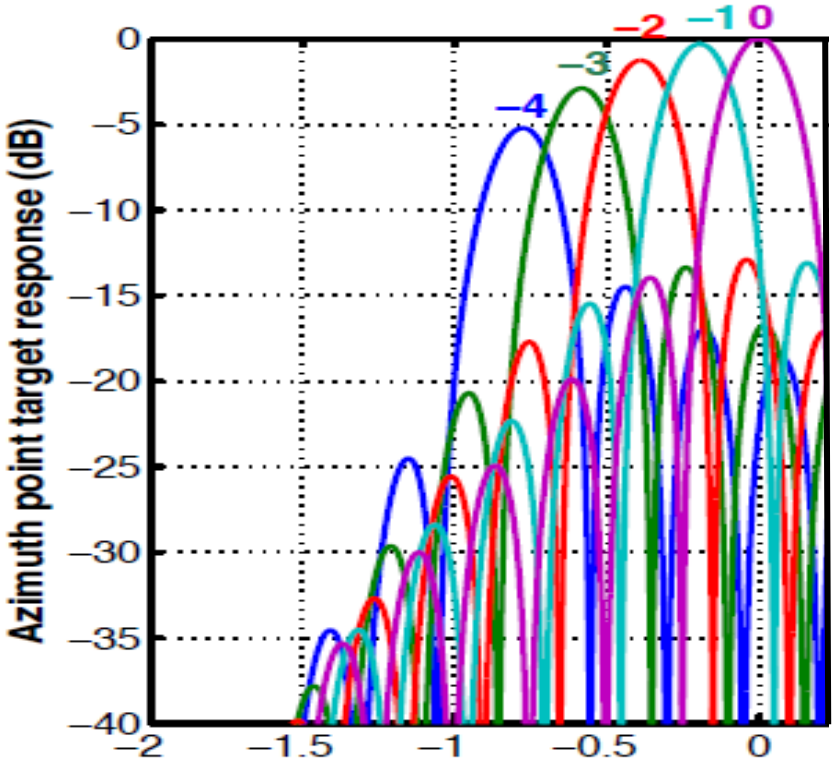
Product	Target User	Contents	MB/granule	
Basic	All SSH/SSHA Users	SSH, SSHA, and most geophysical corrections	<40	1 GB/day
Wind and Wave	All SWH and wind speed Users	Wind speed, SWH, sigma0, and intermediate quantities	<40	1 GB/day
Expert (Includes copies of Basic and Wind and Wave)	Expert Users who want all corrections	All corrections, alternate corrections, and intermediates	120	3 GB/day
Unsmoothed	Expert Users who want full downlinked resolution	500 meter resolution SSH and sigma0 on native 250-m center beam grid	1,500	40 GB/day
L1B	Expert Users who want to redo height reconstruction	Interferograms, sigma0, and volumetric correlation for all 9 beams on reference grids, and all geometry	42,000	1 **TB**/day

Processing steps affecting SWOT resolution

- KaRIN onboard processor smooths interferograms to 500-m resolution/250-m grid (except for 250-m resolution sigma0 image)
- KaRIN instrument has 9 beams that allow 9 independent estima of interferogram (not colocated interpolation needed to combine them)
- L2 processing
  - estimates from 9 beams interpolated to position of center beam
  - estimates from 9 beams combined by weighted average (SNR of squint-angle)
  - spacecraft “native” grid data interpolated to earth-fixed grid
  - SSH smoothed (4-km Hamming filter, ~6.2-km half-power point) and subsampled to 2-km grid

 For most users, further smoothing will be required for noise suppression so the details of the above filtering steps might be inconsequential

 For users who intend to reduce noise from SSHA (e.g. averaging multiple cycles for geodesy), these filtering layers might be important to understand with the ATBD and the unsmoothed product is likely the best option (but it is VERY noisy)



(KaRIn On-Board Processor ATDB , JPL D-79130)

Simulated products & science simulator

- Customizable KaRIN/nadir simulations can be performed with the science simulator (a.k.a portable simulator)
- Pre-constructed data made by the Project and available on PODAAC & AVISO
  - 1 year worth of KaRIN & nadir products
  - Official formats
  - Different flavors: MITgcm or GLORYS or AVISO ocean reference
  - Contain a partial set of corrections and geophysical references (e.g. XCAL, MSS, tides)
  - The rest of the product (e.g. flags, uncertainties) is currently not populated (not implemented in science simulator simulator) Any missing item of interest ?
- As we are close to launch, the Project does not plan to spend more time on simulated data unless the Science Teams has a strong need Any opinion ?

Documentation and links

Entry points

- AVISO: https://www.aviso.altimetry.fr/en/missions/future-missions/swot.html
- PODAAC : https://podaac.jpl.nasa.gov/SWOT?tab=mission-objectives&sections=about
- Links and reference HUB: https://www.aviso.altimetry.fr/en/missions/future-missions/swot/links-and-references-on-swot.html

Documentation

- Product Description documents (PDD) for Level-1 and Level-2 ocean products
  https://podaac.jpl.nasa.gov/SWOT?tab=datasets&discipline=ocean&sections=about%2Bresources
- Algorithm and Theoretical Basis Documents (ATBD) for onboard, L1B and L2 processors

  L1B/L2 processor: ongoing work from Project, first draft reviewed by ADT members

  Onboard processor : https://swot.jpl.nasa.gov/system/documents/files/4216_D-79130_KaRIn_OBP_ATBD_RevA_20171103_URS_Approved_Signed.pdf
- SWOT Mission Performance and Error Budget

  https://swot.jpl.nasa.gov/system/documents/files/2178_2178_SWOT_D-79084_v10Y_FINAL_REVA__06082017.pdf

Simulated products

- Project simulated products:
  (AVISO) http://doi.org/10.24400/527896/a01-2021.006
  (PODAAC) https://podaac.jpl.nasa.gov/SWOT?tab=datasets&discipline=ocean&sections=about%2Bresources
- Science a.k.a Portable simulator: available on GIT hub (Lucile Gaultier is still the point of contact)
- Small scenes from very realistic simulators (NASA/JPL & CNES/CLS for Project, F.Nougier for ST)

Thank you for your attention

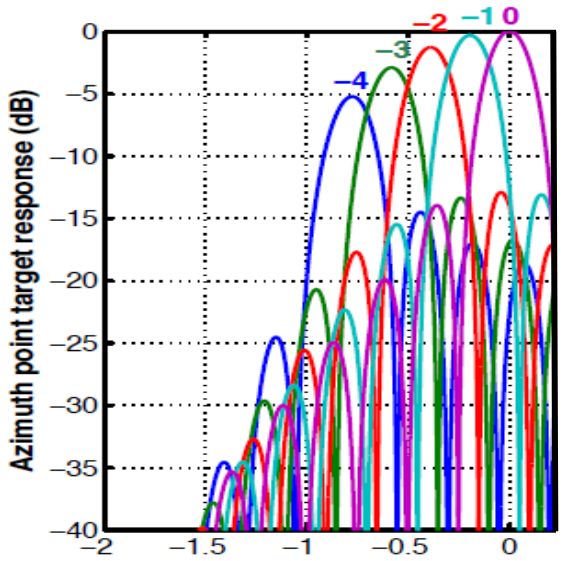
Backup slides

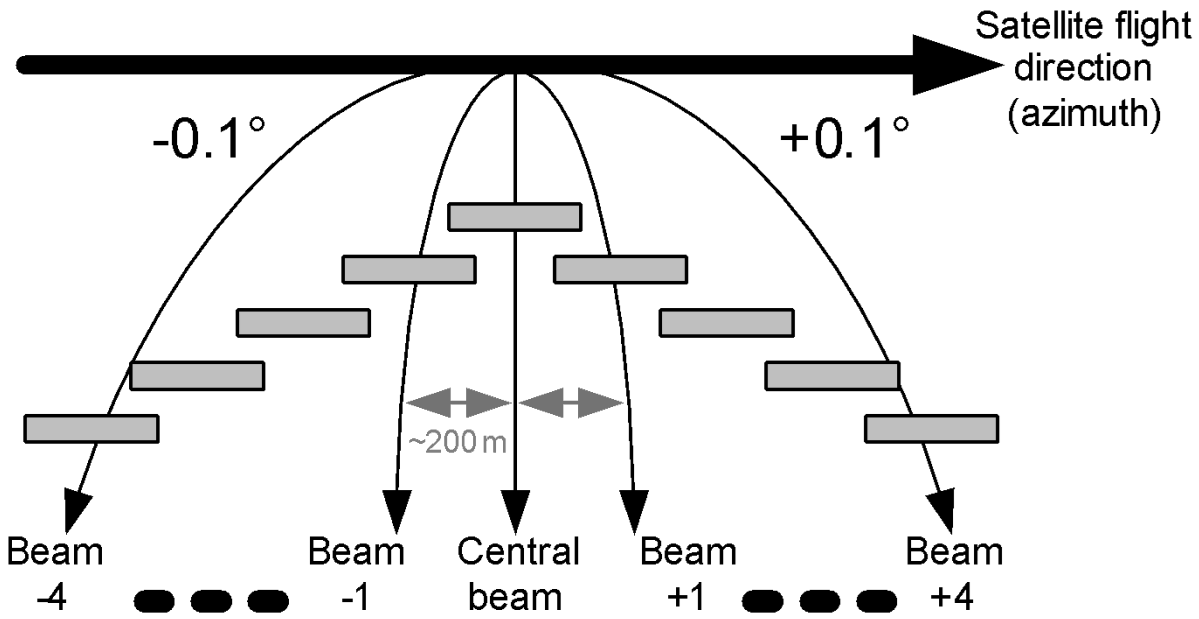
Subject Matter Experts (SME) : ST representatives for algorithms and products reviews

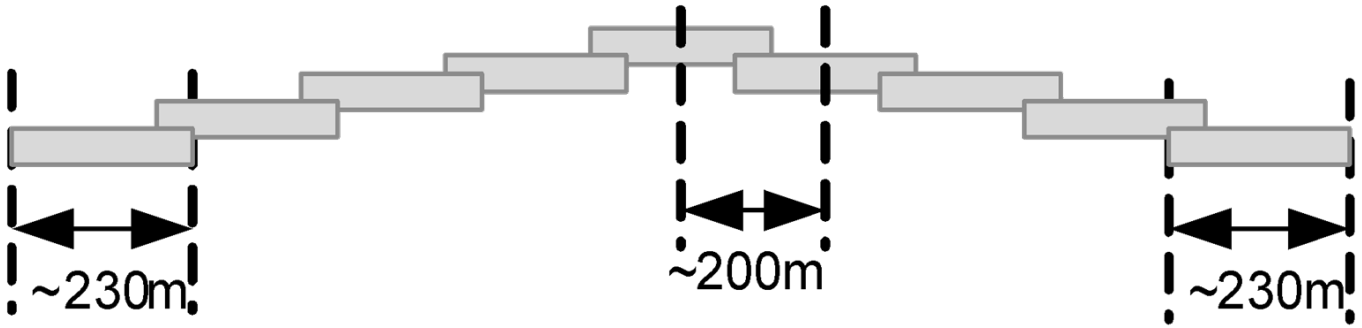
Lead SMEs : Global co-ordination : T. Farrar (US); G. Dibarboure (FR)

Science Algorithm	Description	Subject Matter Experts
L2_RAD_GDR	Generates Level 2 radiometer product with measurements of wet troposphere delay and sigma0 atmospheric attenuation from downlinked data.	S. Brown B. Picard
INT_LR_XOverCal	Generates cross-over calibration product to mitigate systematic errors (e.g., bias, roll/phase, baseline length) from KaRIn and nadir altimeter sea surface height measurements.	E.Rodriguez P.Bonnefond Co-I : C. Watson
L1B_LR_INTF	Generates Level 1B product with 9-beam interferometric, correlation, and power data corrected for instrument effects from 9-beam downlinked data.	F. Nougier Co-I : B. Chapron D. Vandemark
L2A_LR_NativePreCalSSH L2B_LR_FixedPreCalSSH L2A_LR_NativeSSH L2B_LR_FixedSSH	Generates Level 2 sea surface height data products. L2A at KaRIn native center-beam with 2/2 km and 250/500 posting/resolution. L2B on geographically fixed grid with 2/2 km posting/resolution.	S. Gille Co-I : Ed Zaron E.Cosme Co-I : E. Salameh & N. Ayoub

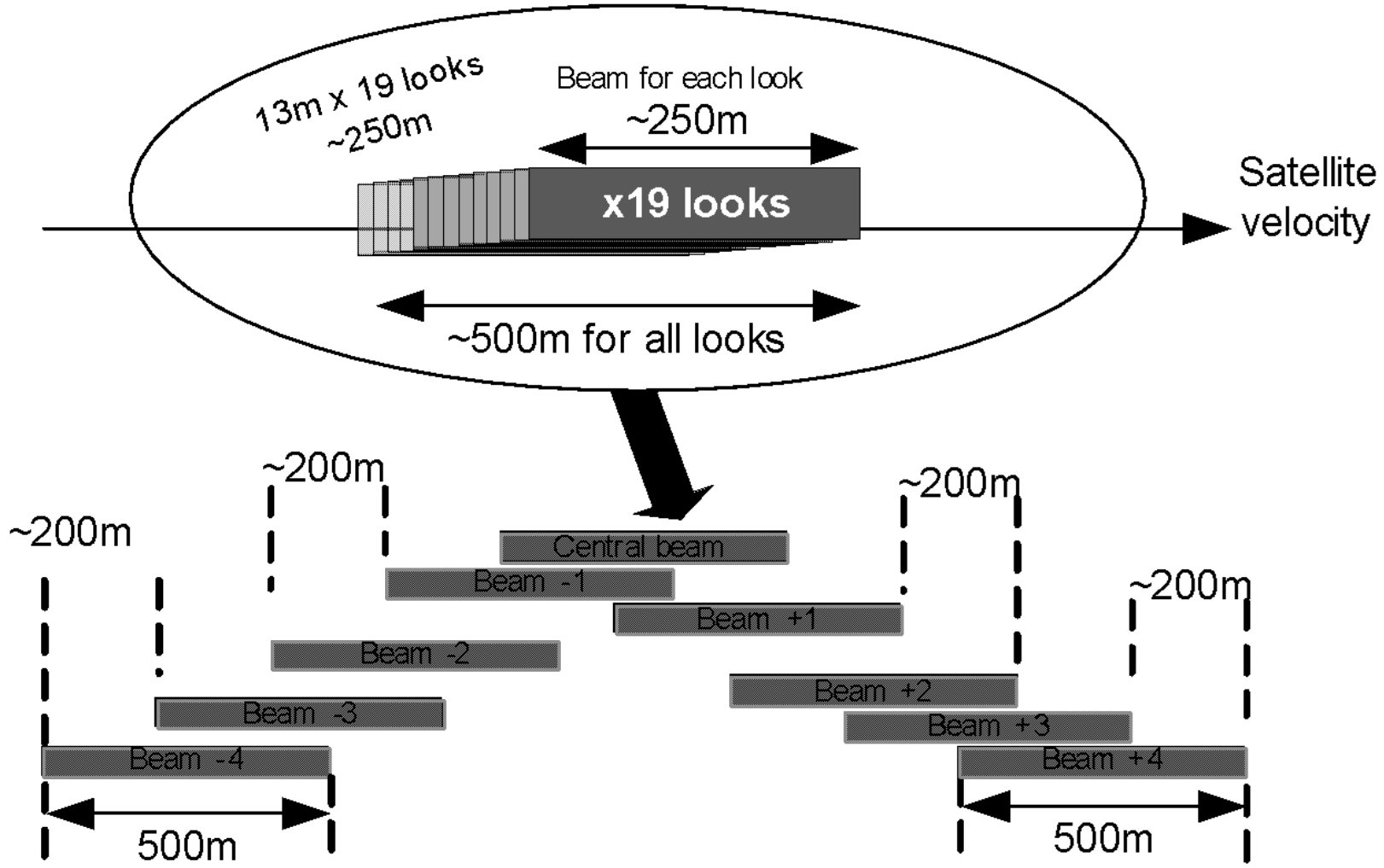
Azimuth SAR processing







OBP output: 500-m pixels x 9 beams



- The 1 km onboard product is built by average a large number of 250 pixels
- In practice, the azimuth averaging uses a larger window (~1km) with Blackman-Harris weights that yield the same number of looks

SWOT's error budget (allocations)

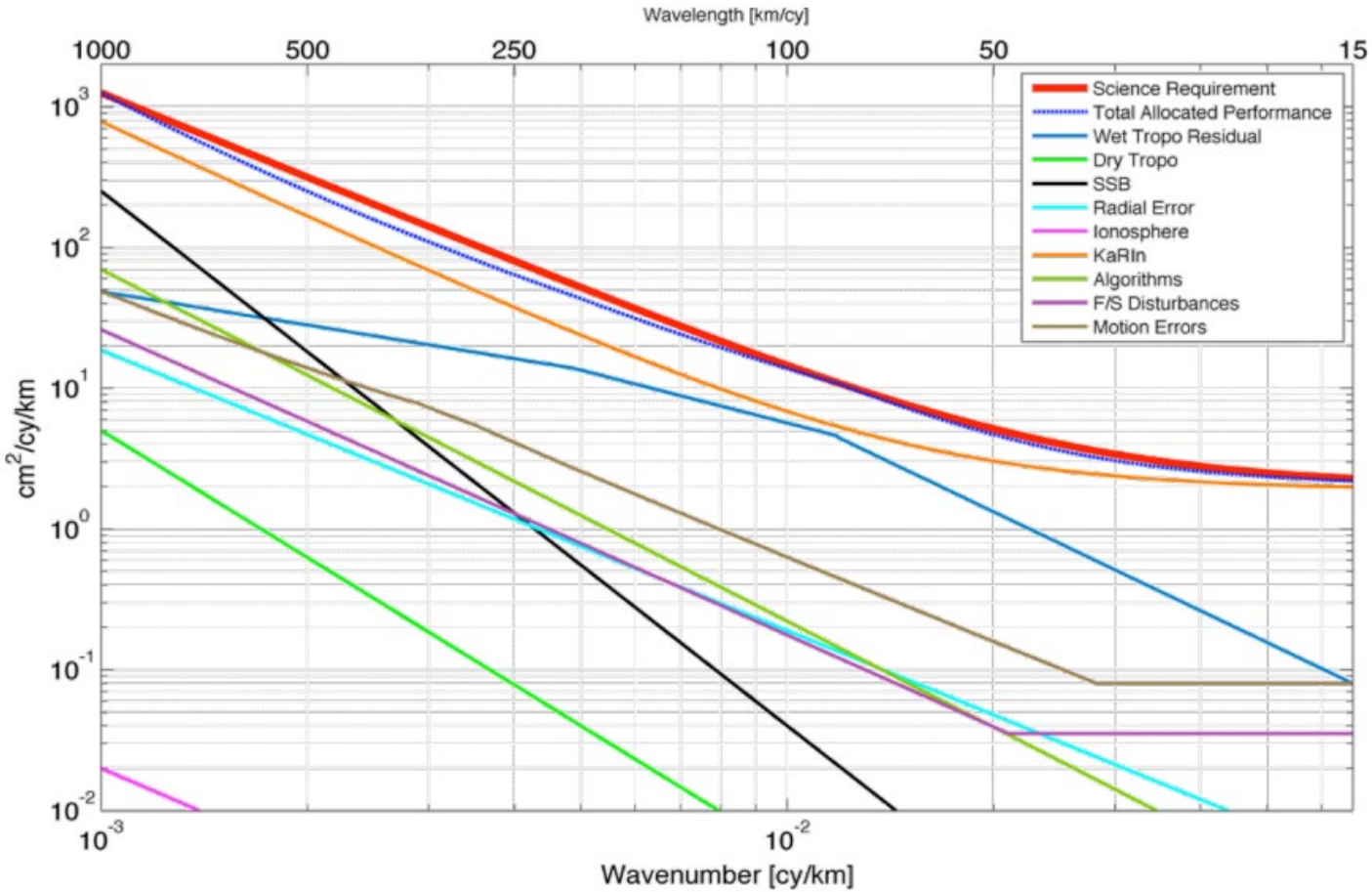
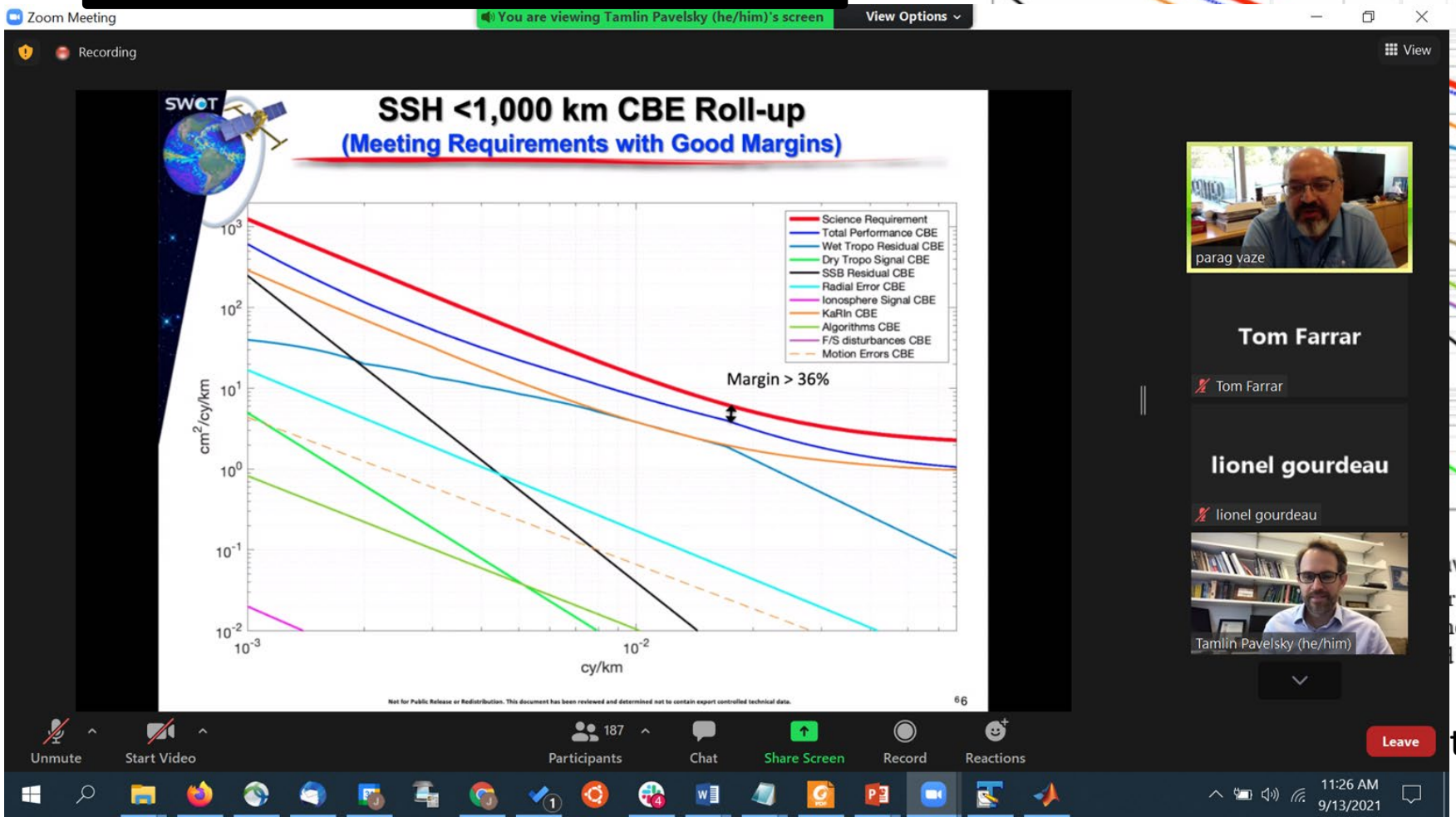


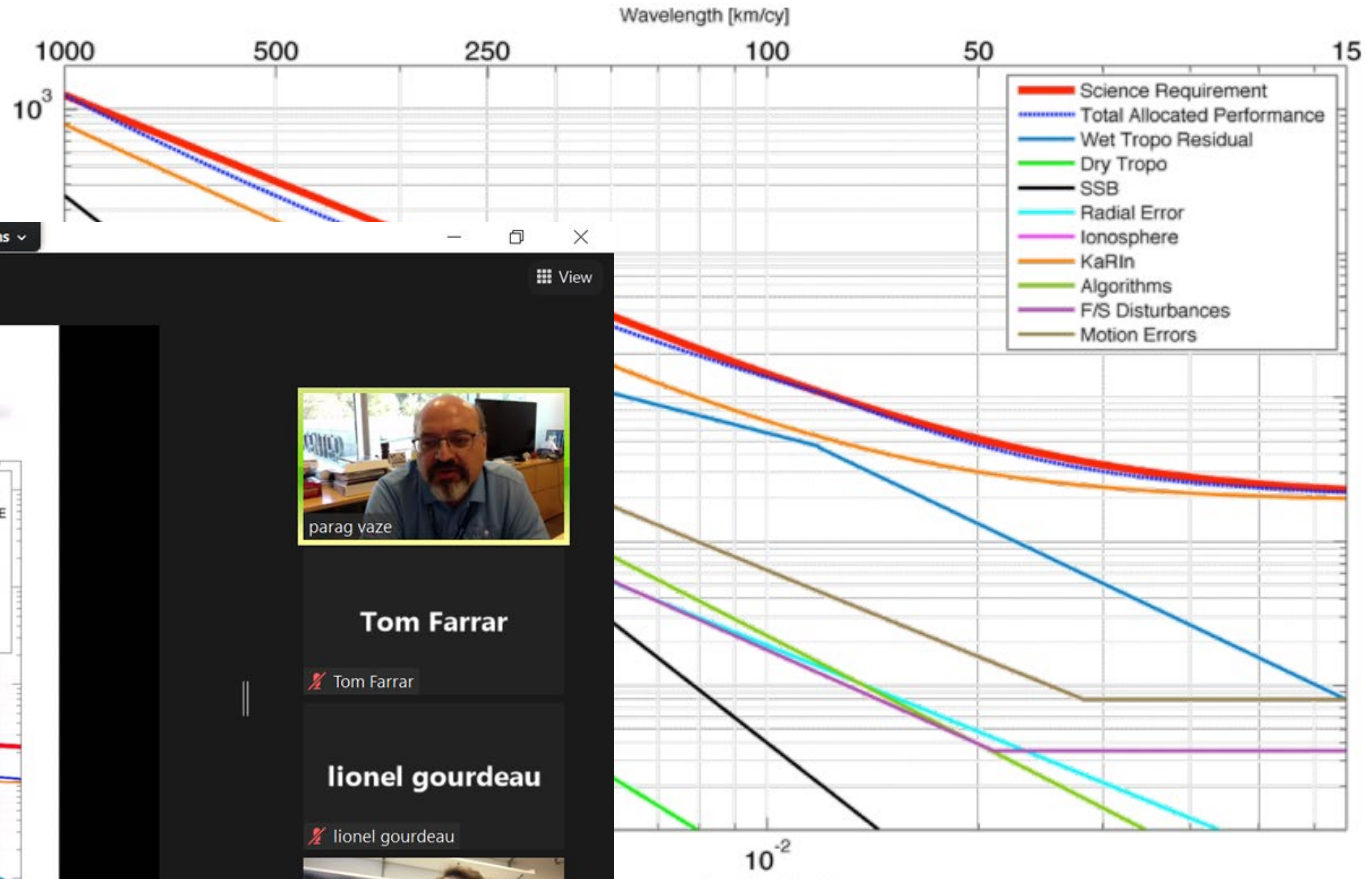
Figure 9. Break-down of the overall SSH error budget for spectral form for wavelengths < 1,000km. This includes all propagation, media, radial, and the sum of all KaRIn errors. Note the KaRIn measurement includes S/C contributions such as pointing and F/S disturbances.

(Error budget document, JPL D-79084)

SWOT's error budget (allocations)

As we saw yesterday, current best estimate is that SWOT LR data will outperform requirements by >36%!



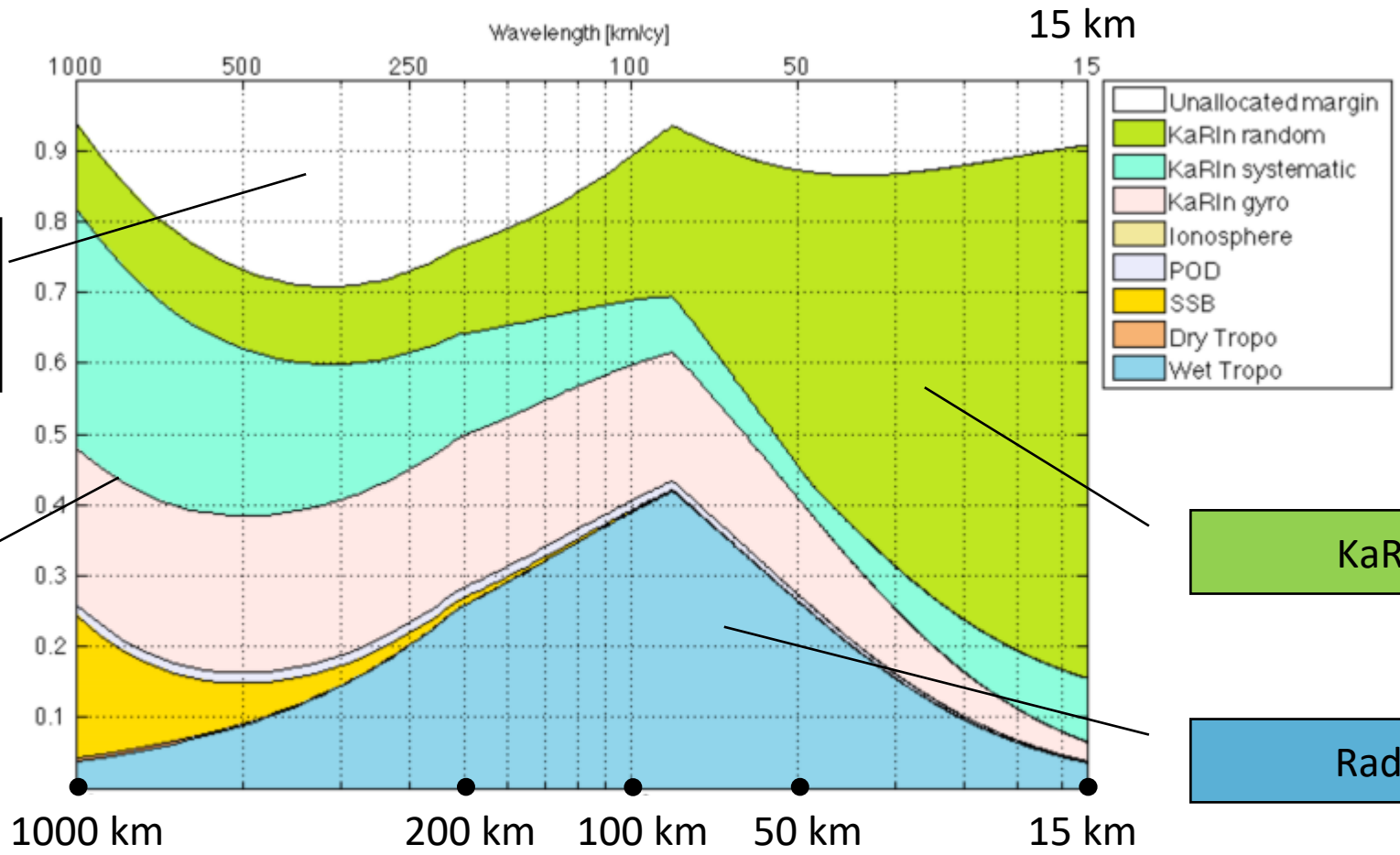


venumber [cy/km]

r budget for spectral form for wavelengths < 1,000km. This
e sum of all KaRIn errors. Note the KaRIn measurement
l F/S disturbances.

t document, JPL D-79084)

The dominating error source changes with scales



Project margins
(to account for new & underestimated errors)

Gyro & KaRIn biases

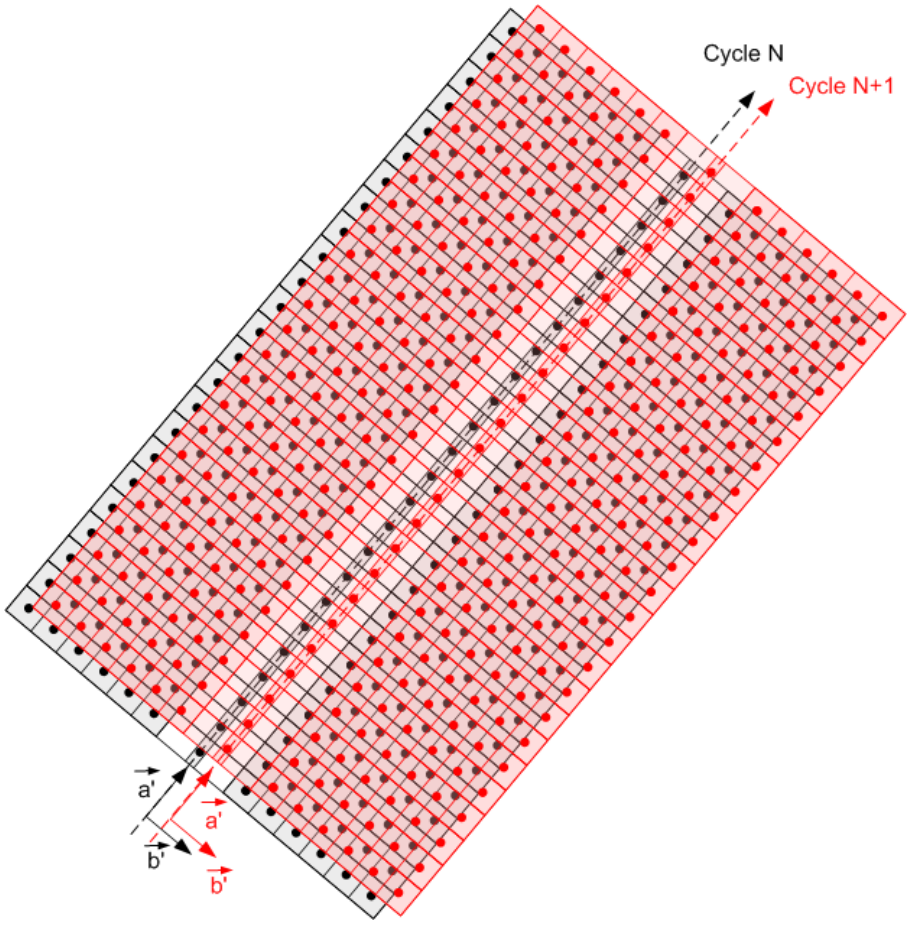
KaRIn noise

Radiometer

Figure 11. Stack-up of the most significant allocations as a fraction of the total SSH requirement as a function of wavenumber.

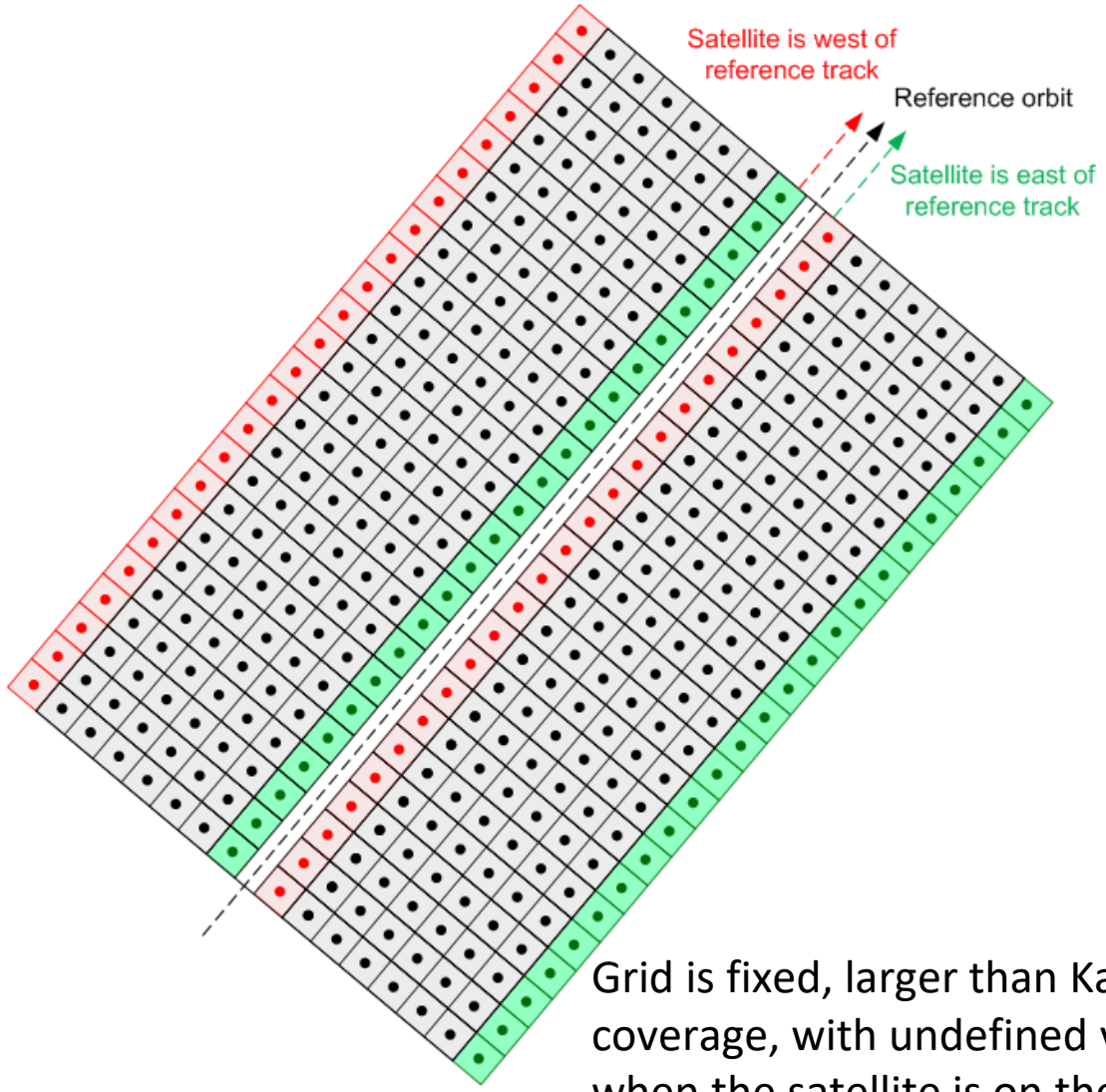
(Error budget document, JPL D-79084)

Swath-oriented native grid (L2A)



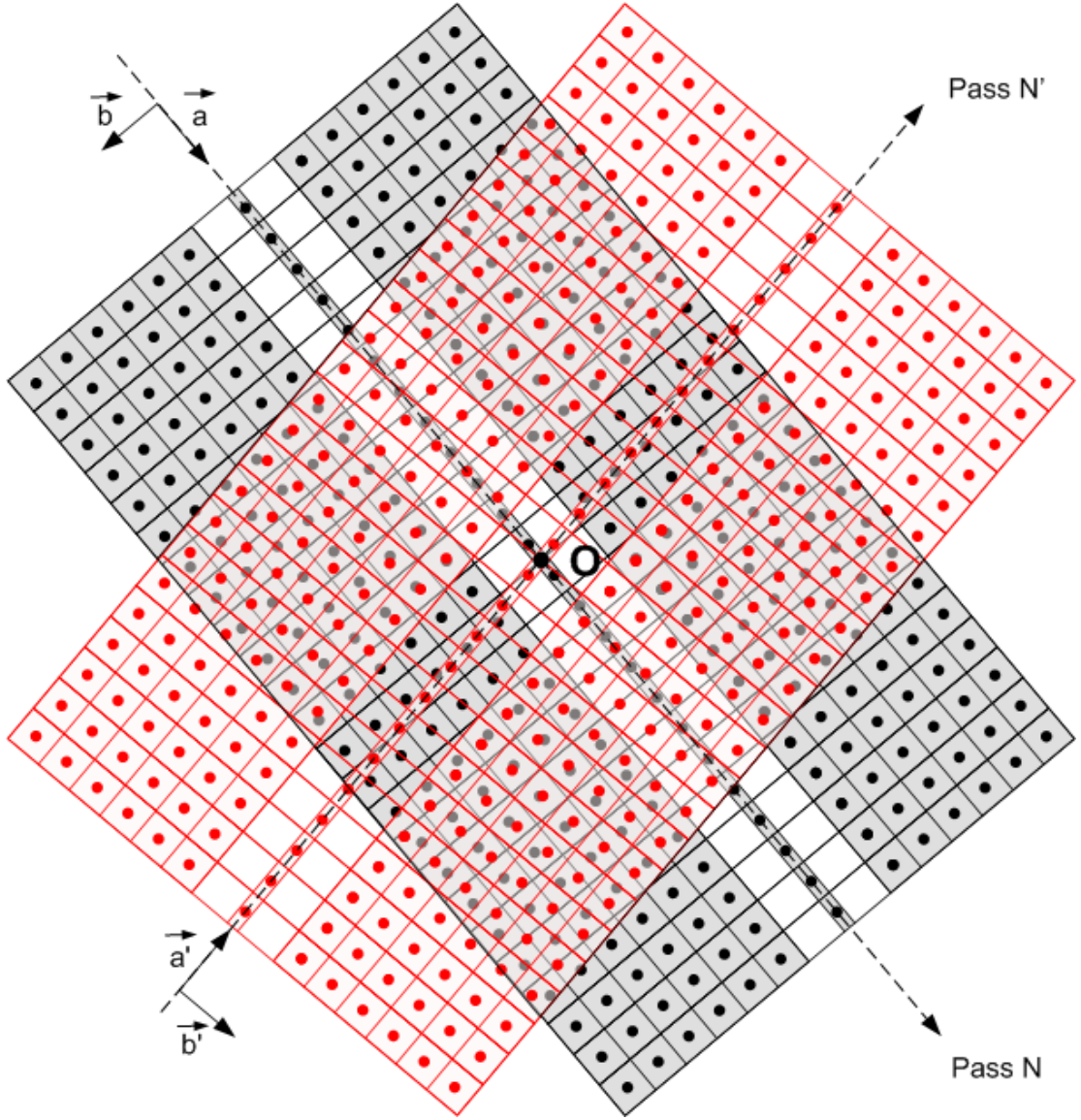
Grid moves with satellite position for each cycle

Swath-oriented fixed grid (L2B)



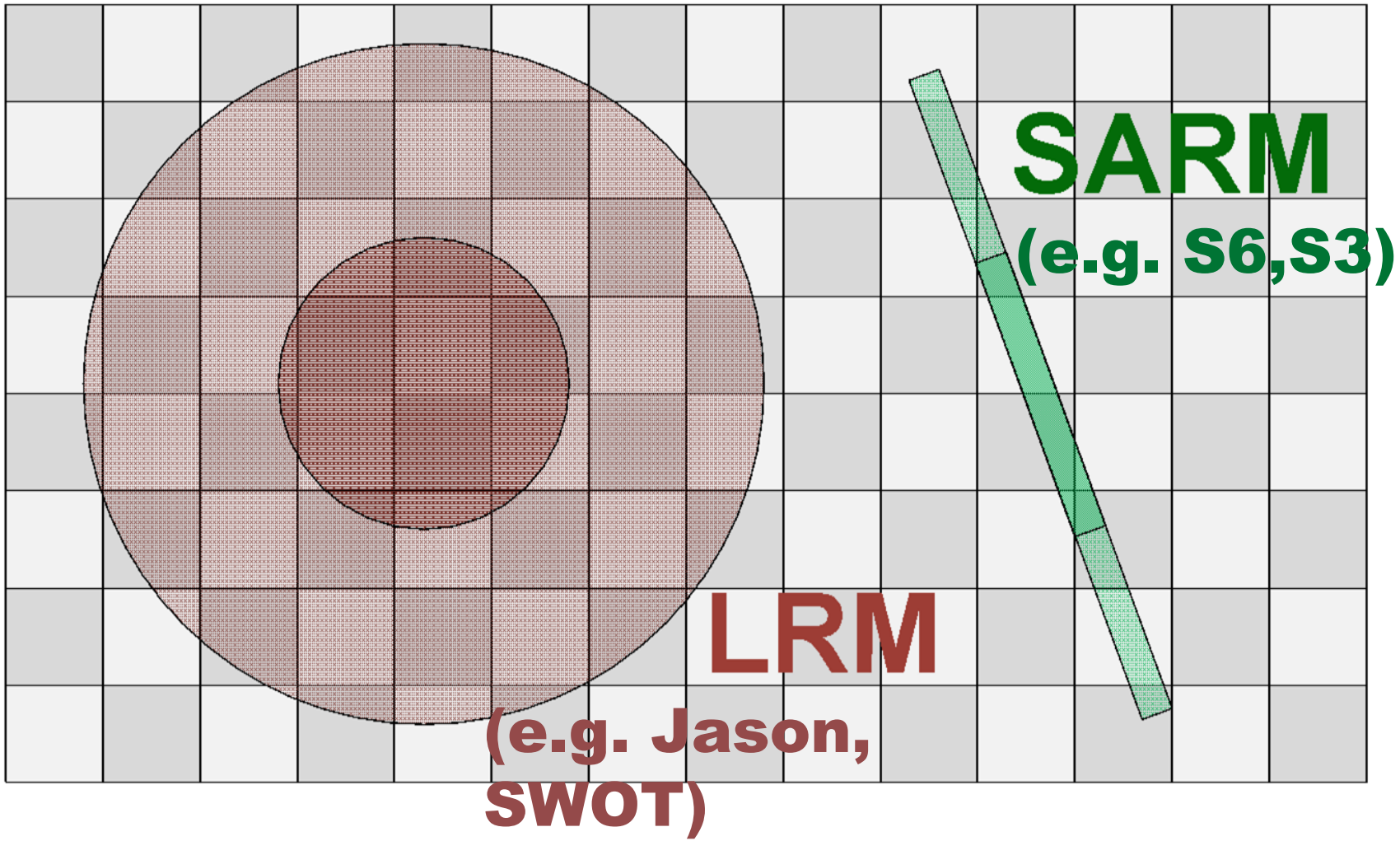
Grid is fixed, larger than KaRIn coverage, with undefined values when the satellite is on the other

Fixed grids have 2 different geometries in cross-overs



Keep in mind pixel sizes when comparing SWOT with nadir altimetry or in-situ

Nadir altimetry footprints over a 1 km grid



KaRIn products

- 20 km (radiometer)
- 2 km
- 500 m
  (posted at 250 m)
- 250 m (σ_0 only)

Nadir products

- 1.5 km (leading edge)
- 7 km (trailing edge)
  (posted at 300 m or 6 km)