SWOT LR algorithm and products

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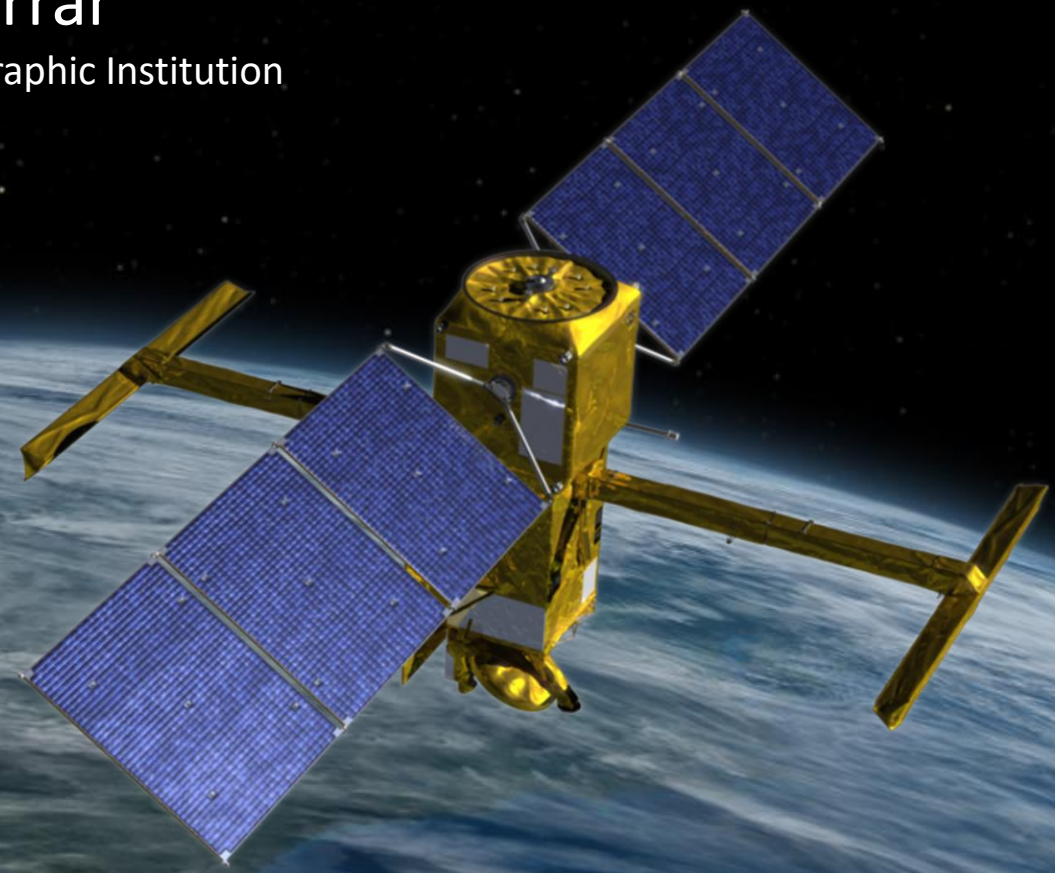


SWOT Science Team Meeting
2021 September 14

Purpose

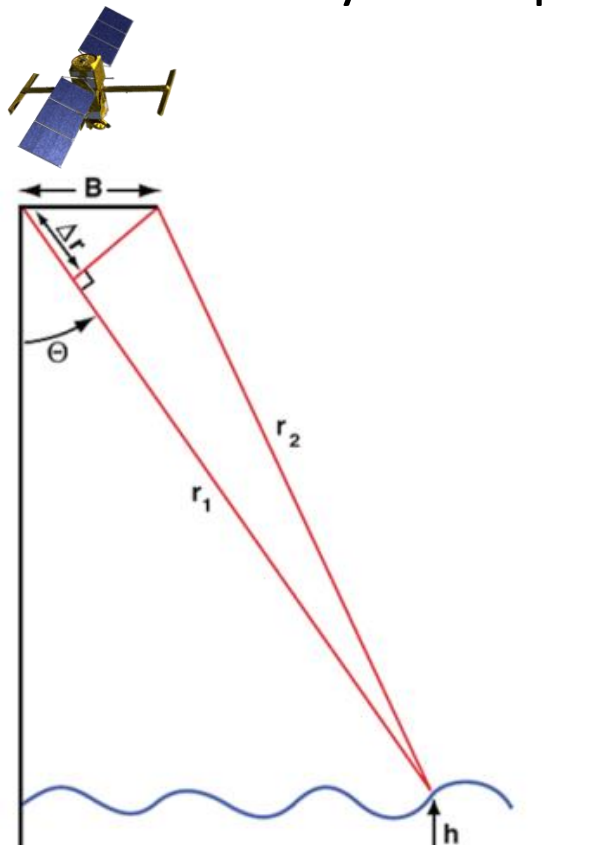
- High-level overview of SWOT “Low-Rate” (LR) algorithm and products
- Discussion of errors (i.e. why the science simulator is useful)

Essential references listed in these slides

- Product Description Documents (PDD)
- Algorithm and Theoretical Basis Documents (ATBD)
- Error budget document, JPL D-79084

SWOT concept in 2 pictures and 2 documents

The basic interferometry concept is simple

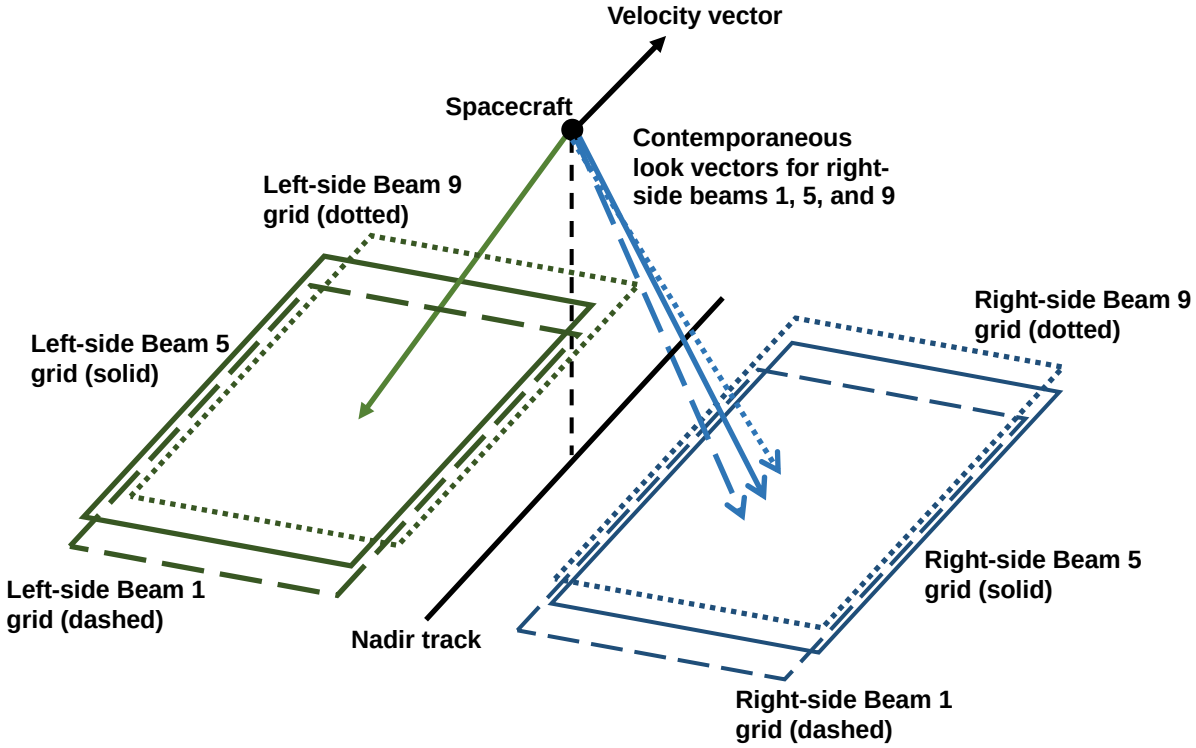


$$\varphi = 2kr_1 - k(r_1 + r_2) \approx kB\sin(\theta)$$

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

(Error budget document, JPL D-79084)

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



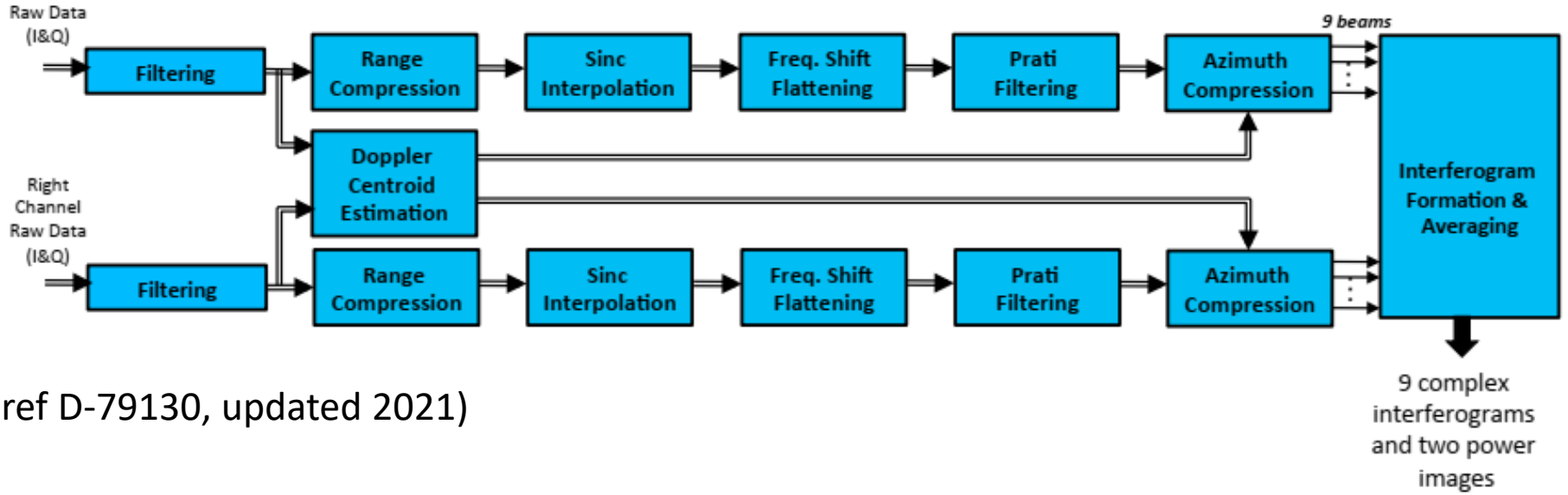
(LR L1B Product Description Document, JPL D-56405)

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: POD, XCAL, and RAD processors

Onboard processor (OBP): ATBD available



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

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)

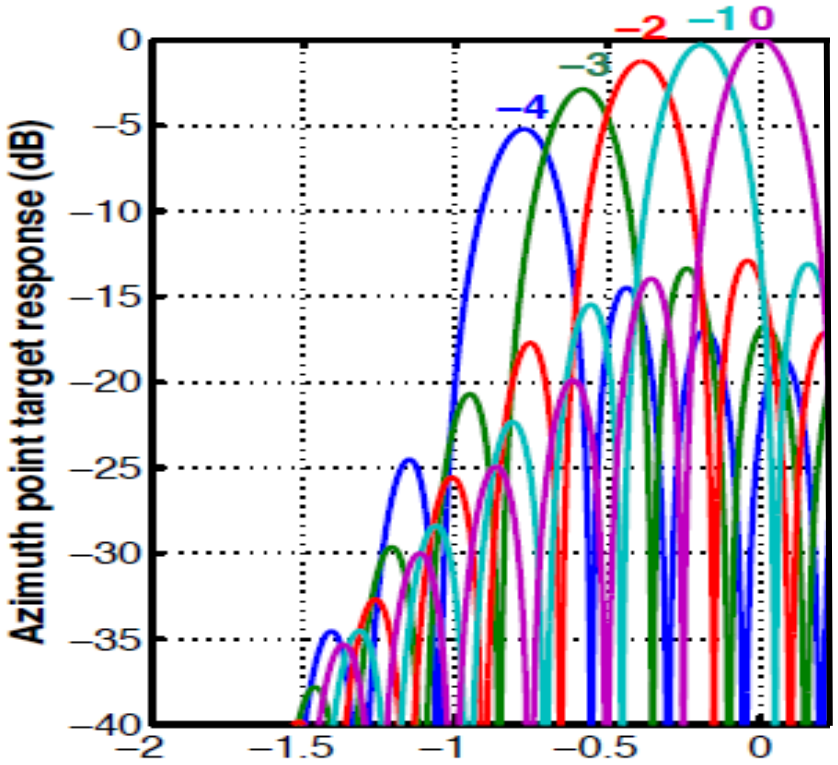
- Radar range ~ cross-track direction
- Azimuth ~ along-track direction

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

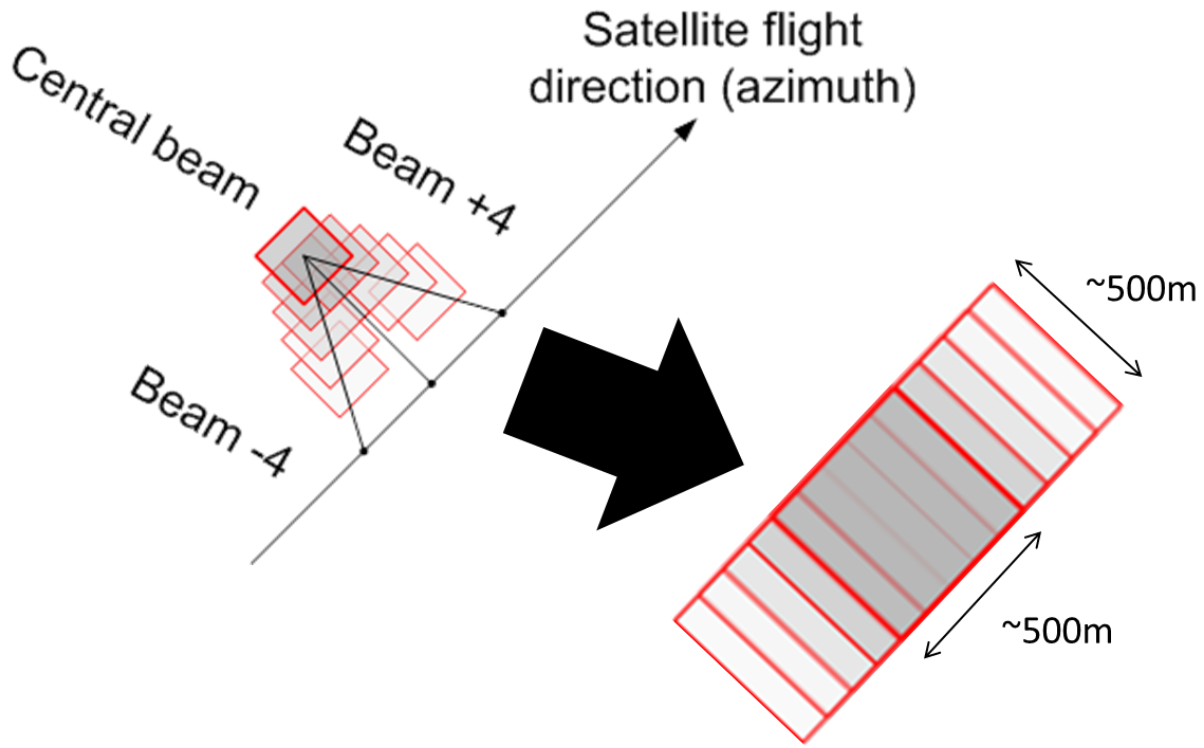
Highlights of onboard and ground processing

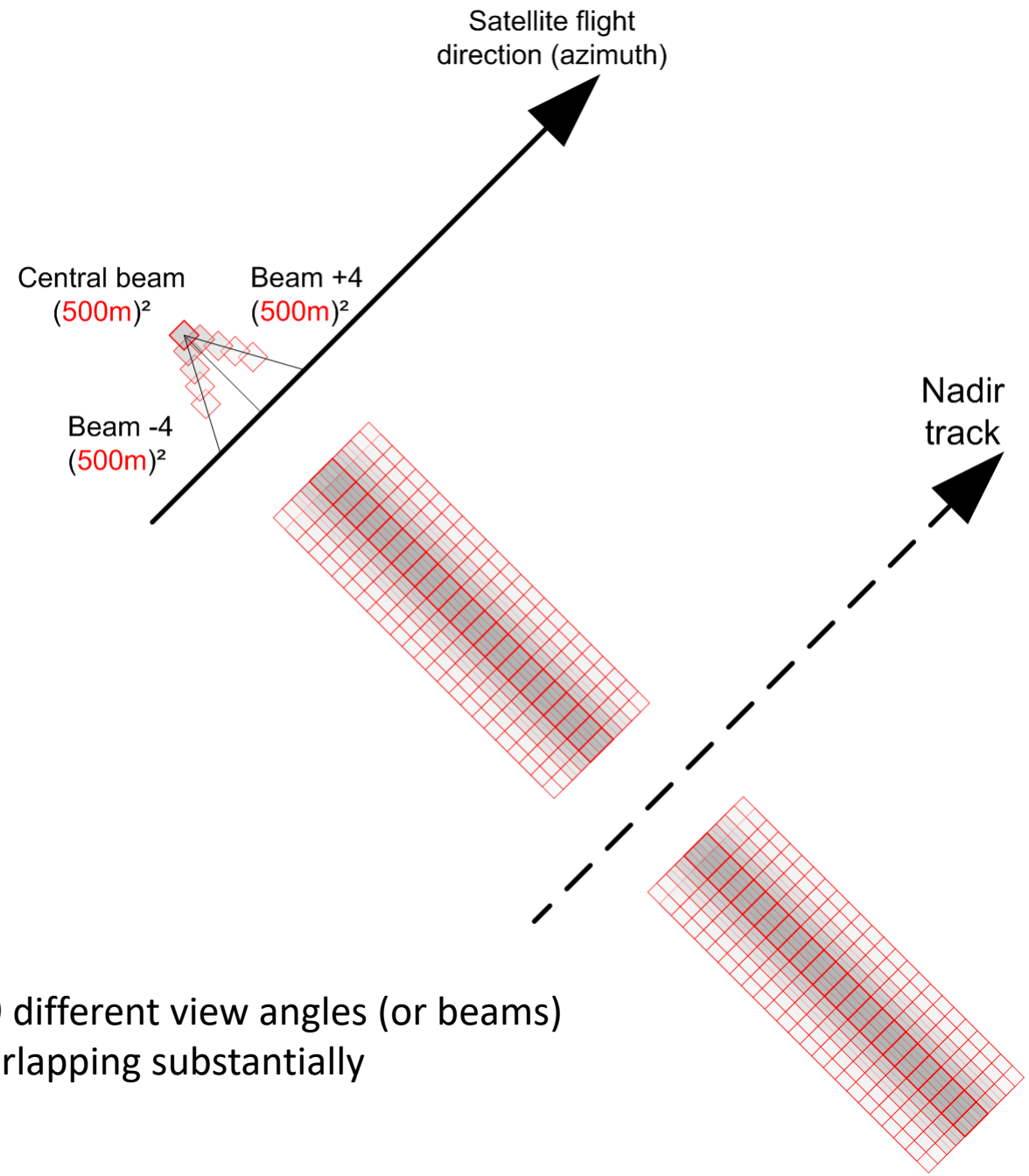
Unfocused SAR processing (Doppler beam sharpening)

From 3 km antenna footprint to 500 m synthetic footprint

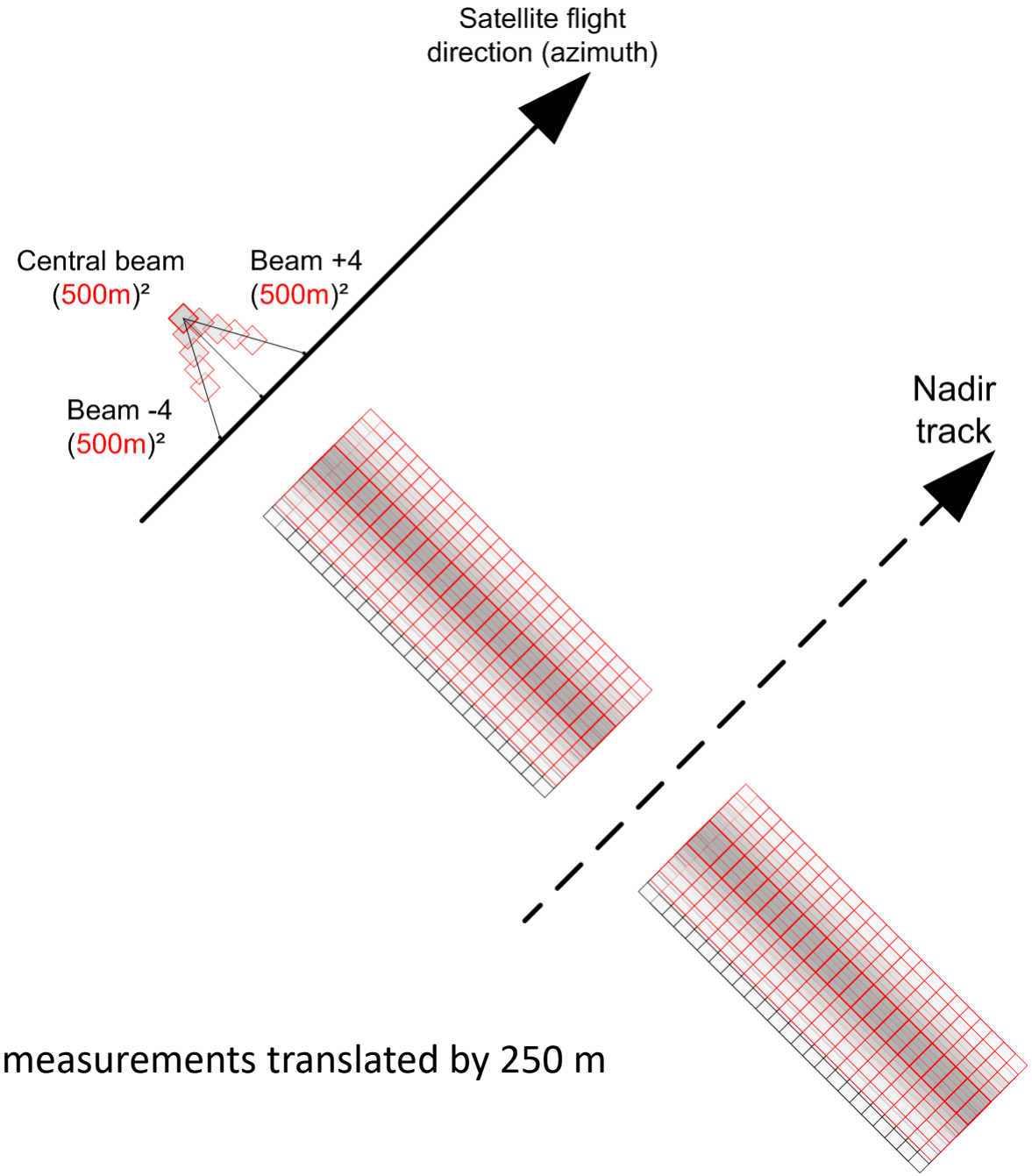


(KaRIn On-Board Processor ATDB , JPL D-79130)

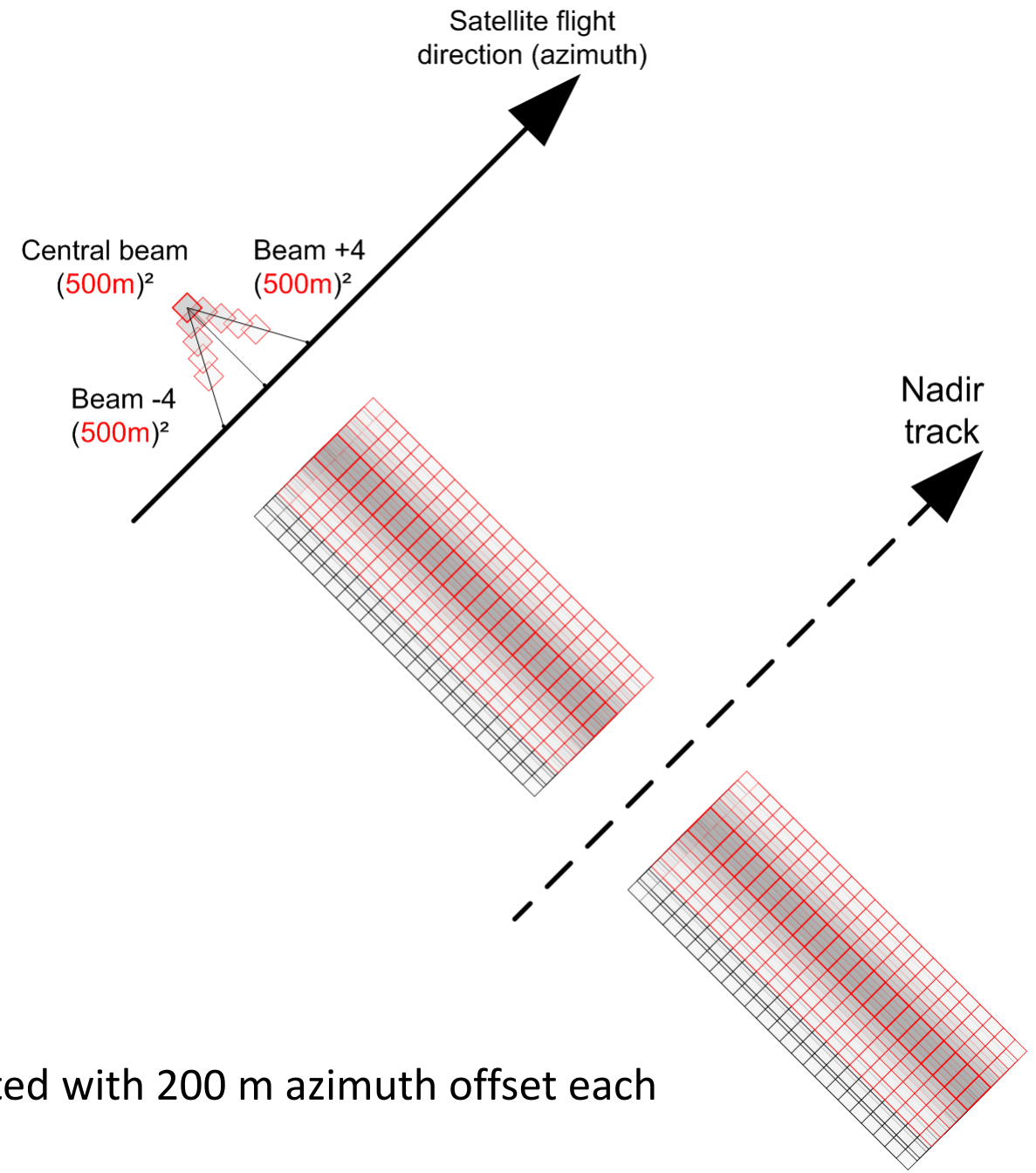




9 lines from 9 different view angles (or beams)
Pixels are overlapping substantially



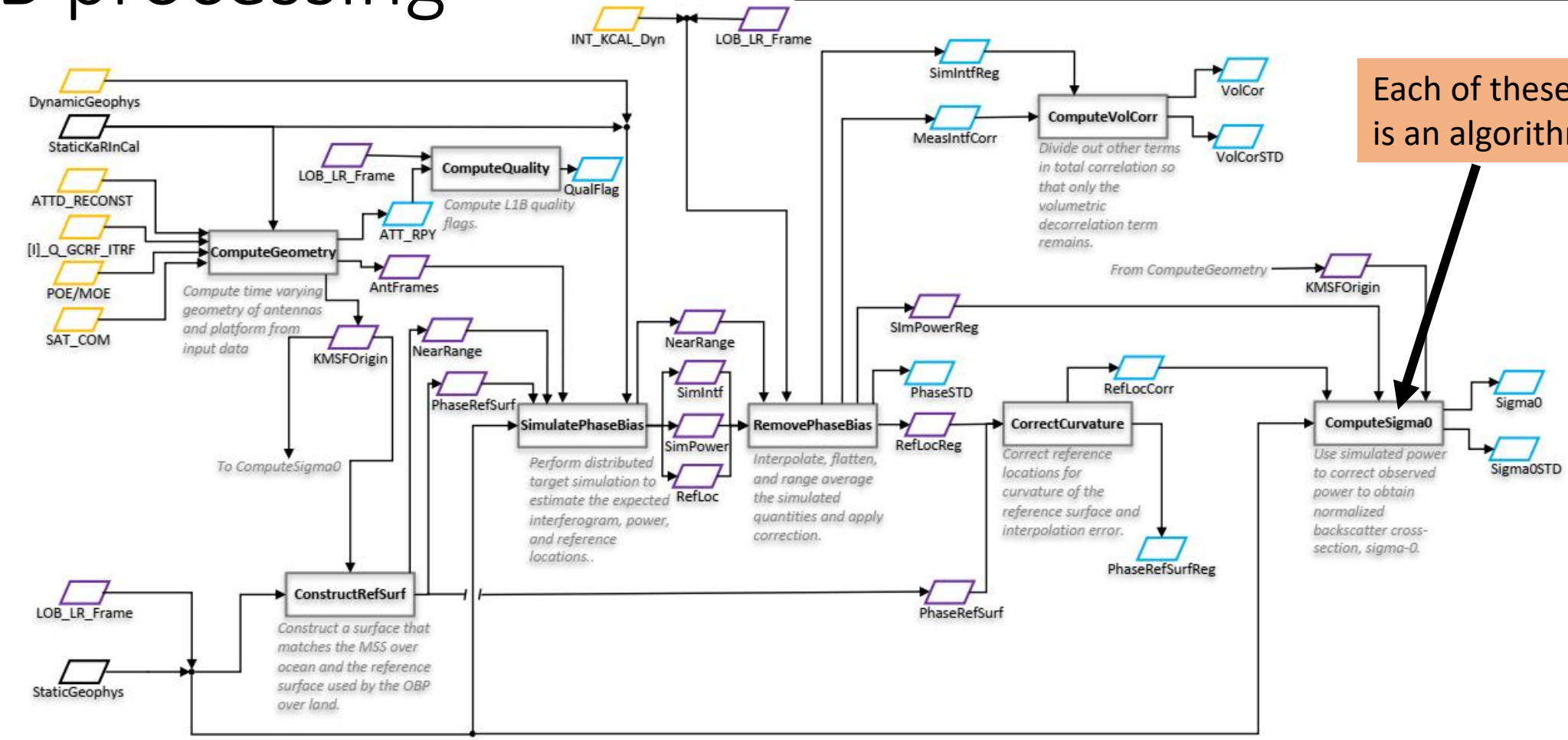
Subsequent measurements translated by 250 m



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

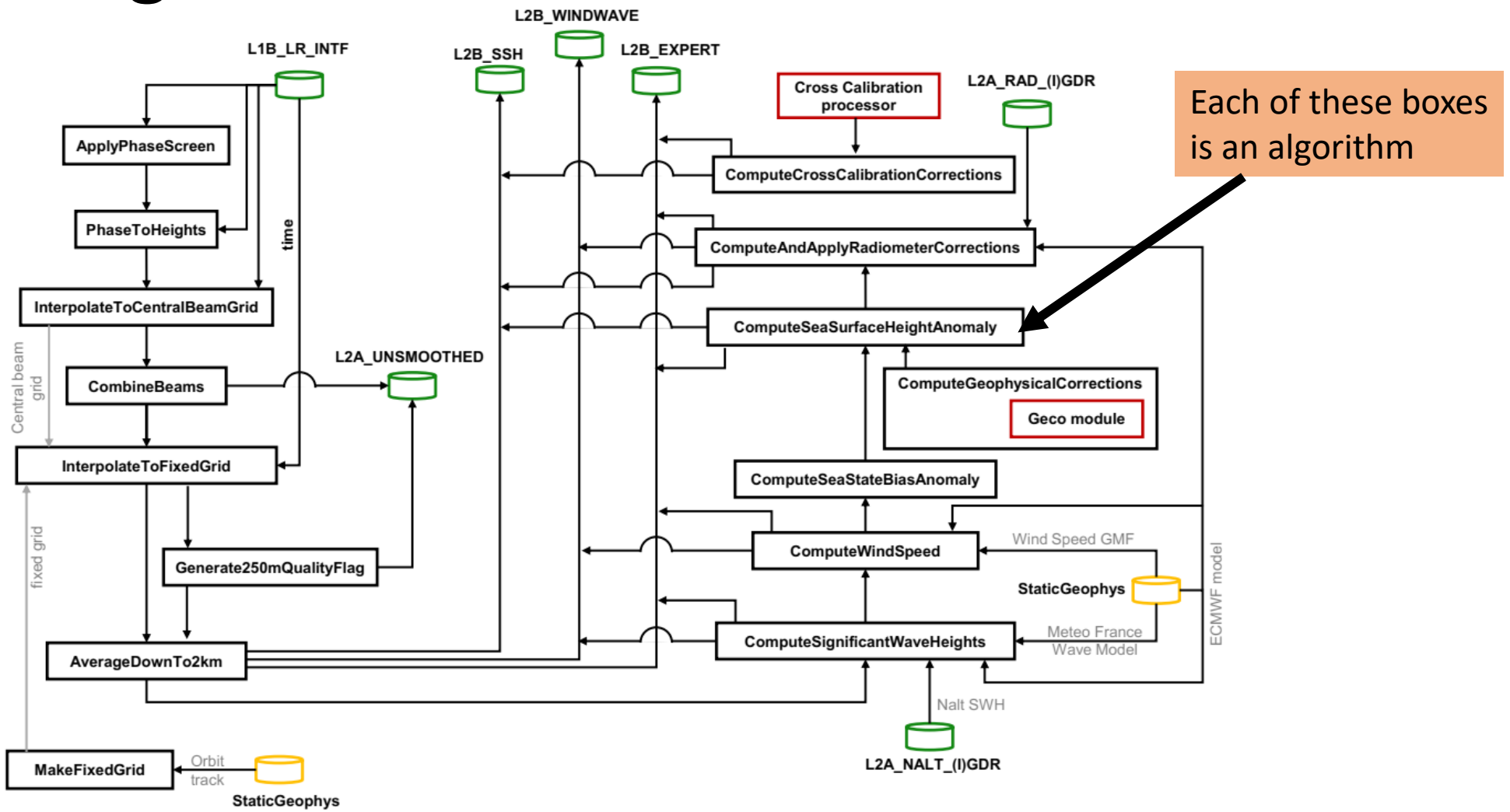


Output: 9 beams and interferograms (not SSH), Sigma0, volumetric decorrelation, geolocation

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

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



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)

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 estimates of interferogram (but they are not colocated → interpolation needed to combine them)
- L2 processing
  - estimates from 9 beams interpolated to position of center beam (so-called “native” grid)
  - 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

SWOT's error budget (allocations)

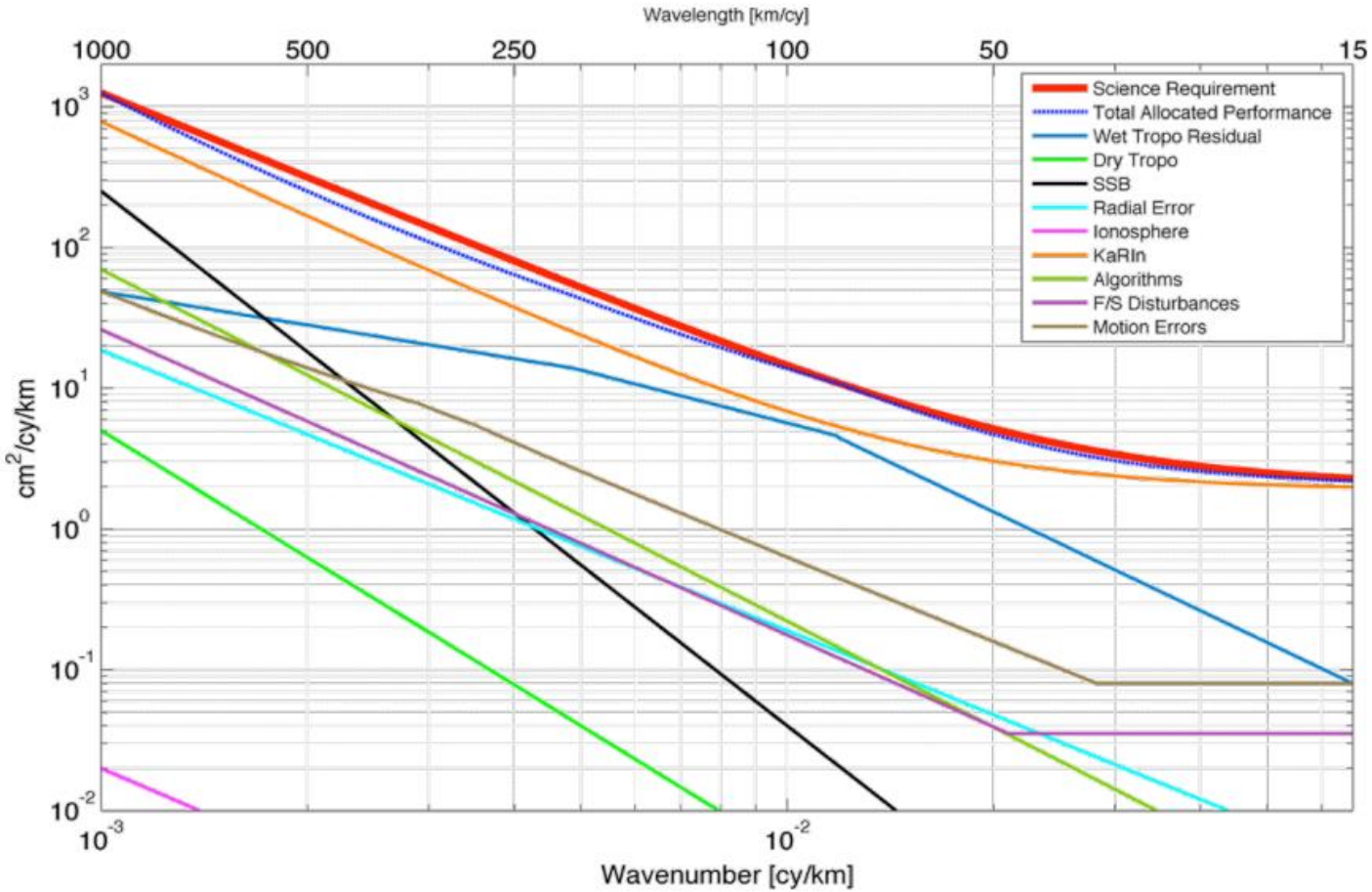
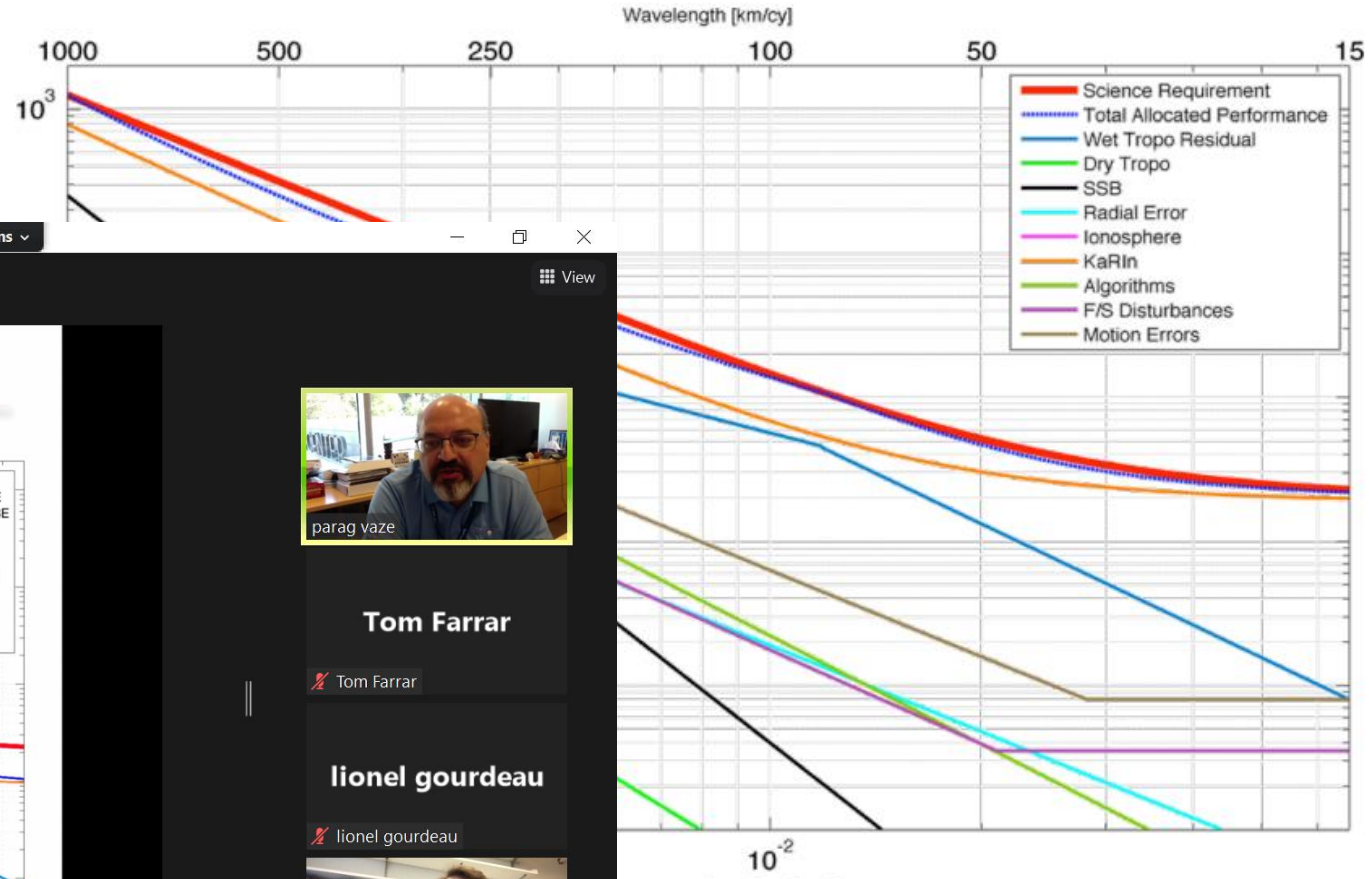


Figure 9. Break-down of the overall SSH error budget for spectral form for wavelengths < 1,000km. This includes all propagation, media, radial, and the sum of all KaRIn errors. Note the KaRIn measurement includes S/C contributions such as pointing and F/S disturbances.

(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%!



r budget for spectral form for wavelengths < 1,000km. This
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l F/S disturbances.

t document, JPL D-79084)

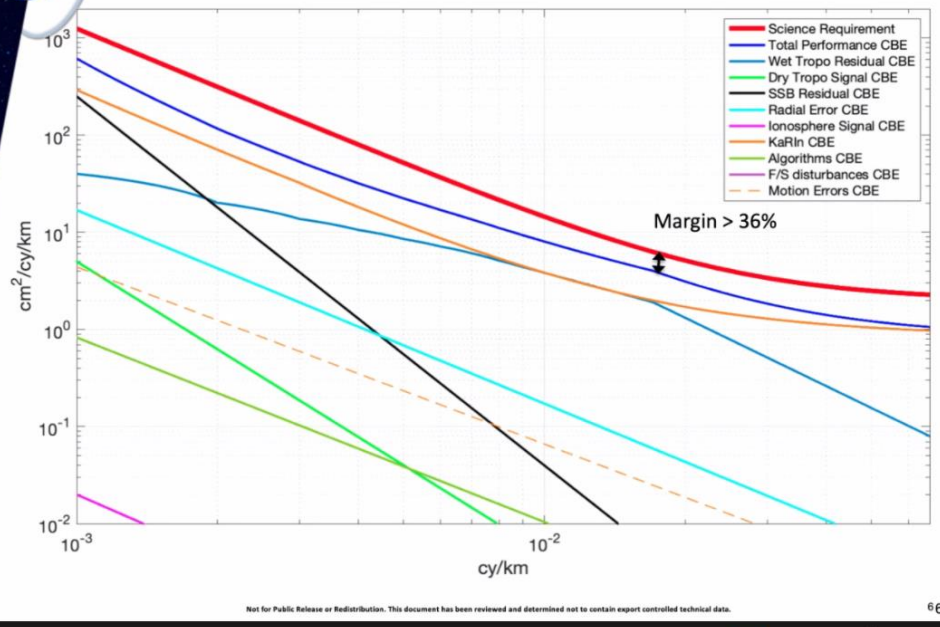
Zoom Meeting — You are viewing Tamlin Pavelsky (he/him)'s screen — View Options

Recording — View

SWOT

SSH <1,000 km CBE Roll-up

(Meeting Requirements with Good Margins)



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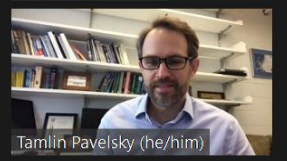
Tom Farrar

Tom Farrar

lionel gourdeau

lionel gourdeau



Unmute | Start Video | 187 Participants | Chat | Share Screen | Record | Reactions | Leave

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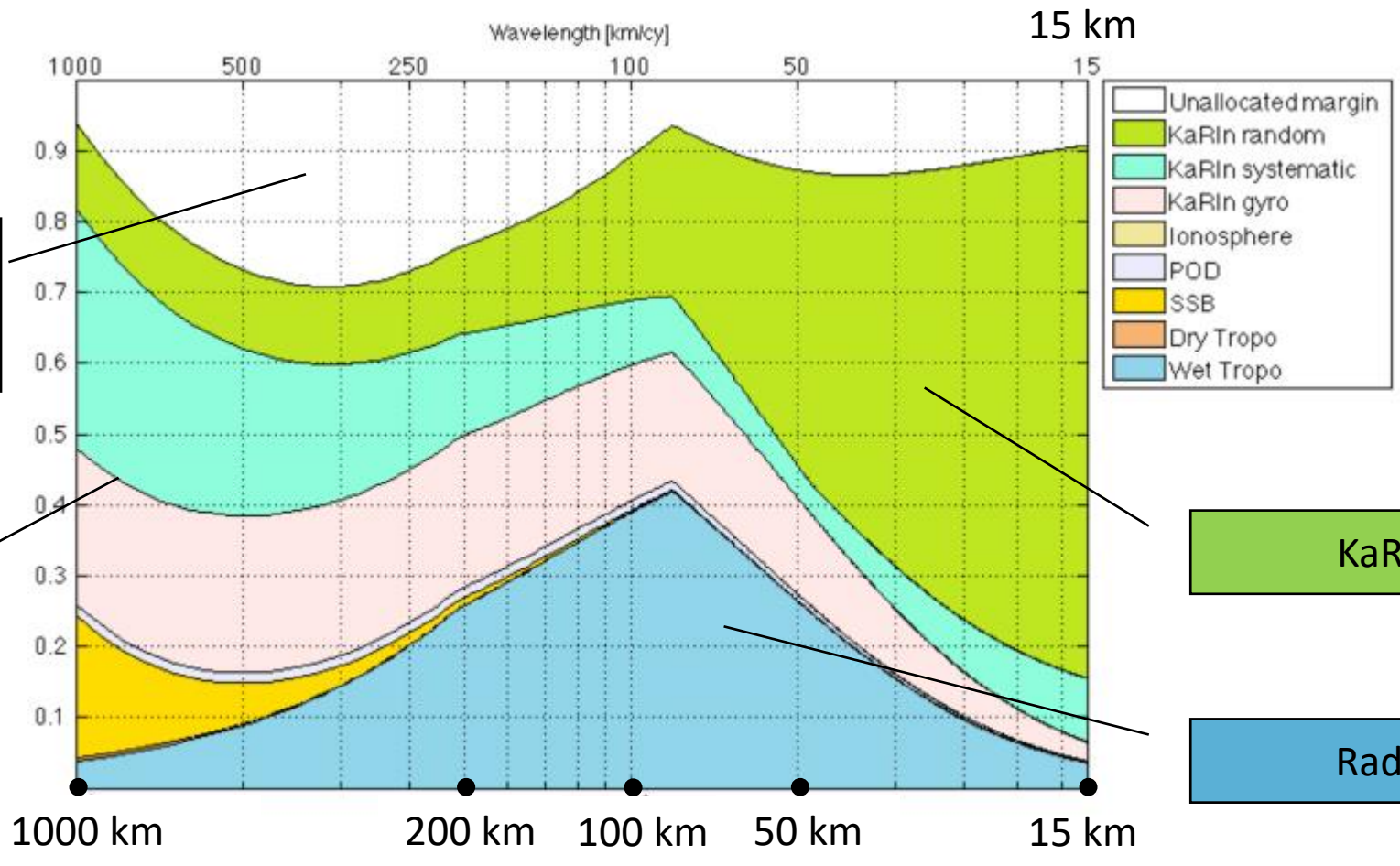
The dominating error source changes with scales



Project margins
(to account for new & underestimated errors)

Gyro & KaRIn biases

KaRIn noise

Radiometer

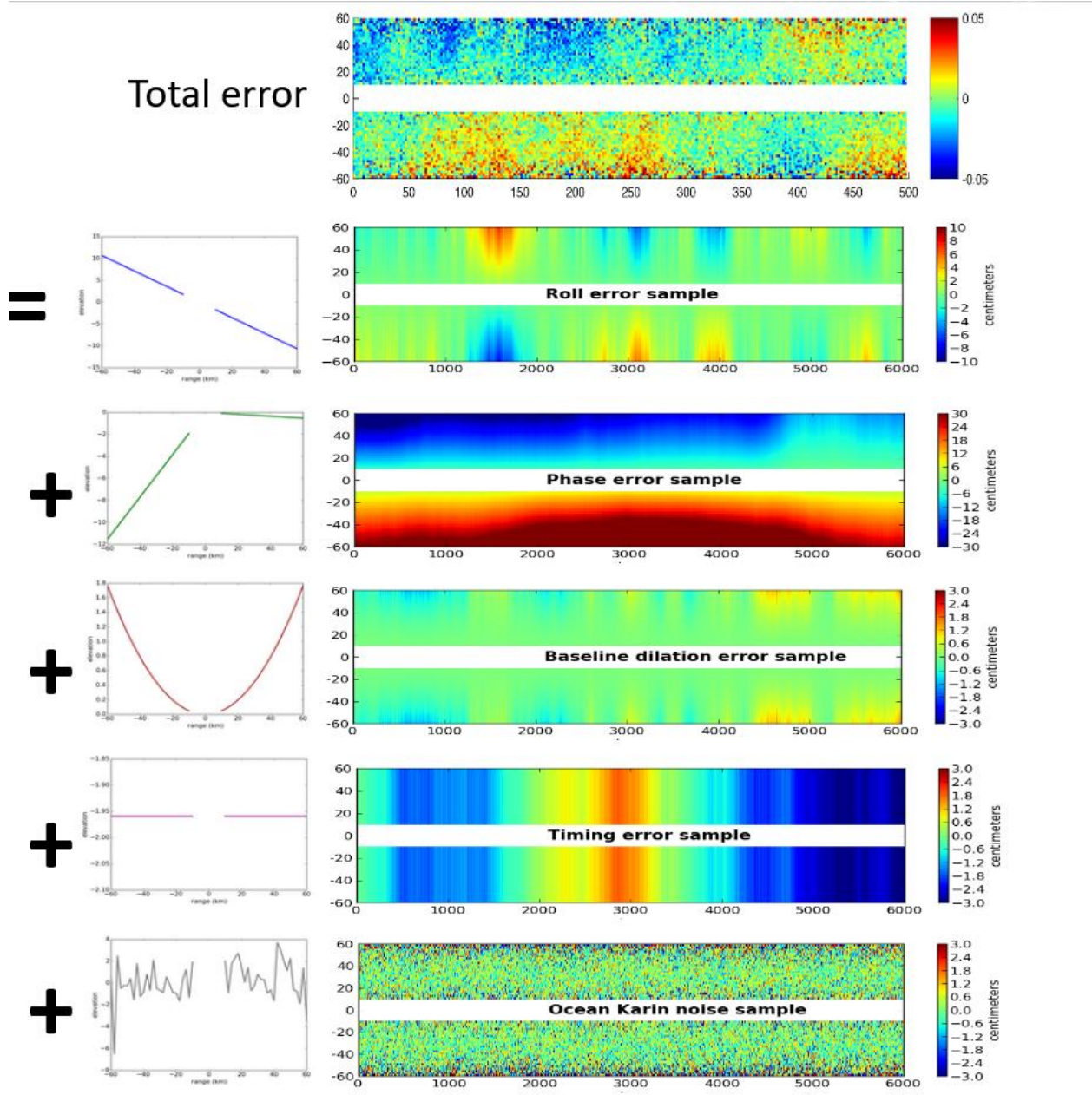
Figure 11. Stack-up of the most significant allocations as a fraction of the total SSH requirement as a function of wavenumber.

(Error budget document, JPL D-79084)

Errors can be anisotropic and spatially correlated

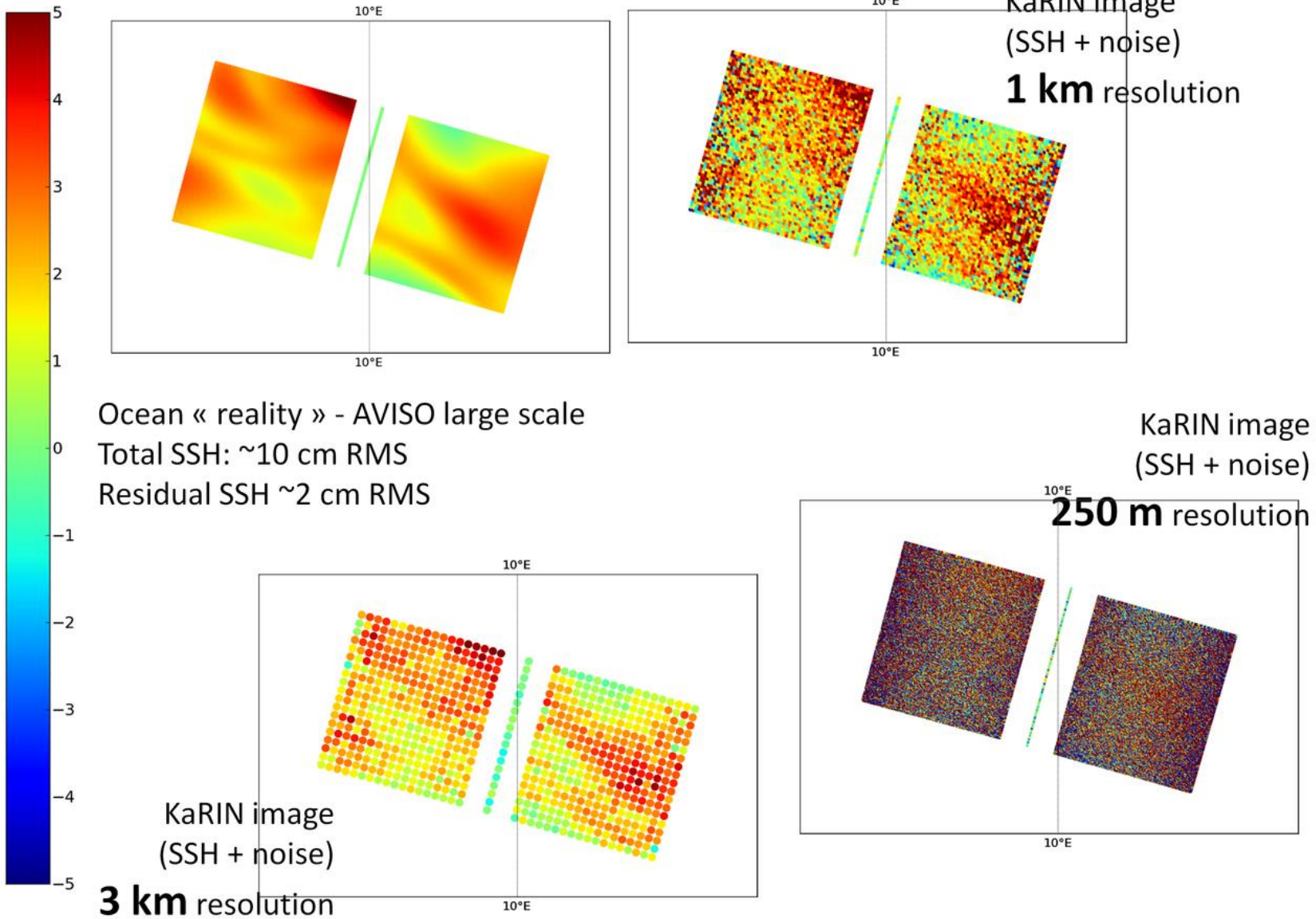
Errors shown here
- Roll / gyro
- Systematic errors
- Noise

Errors not in the picture
- SSB
- Wet troposphere
- Tides / Internal tides
- MSS

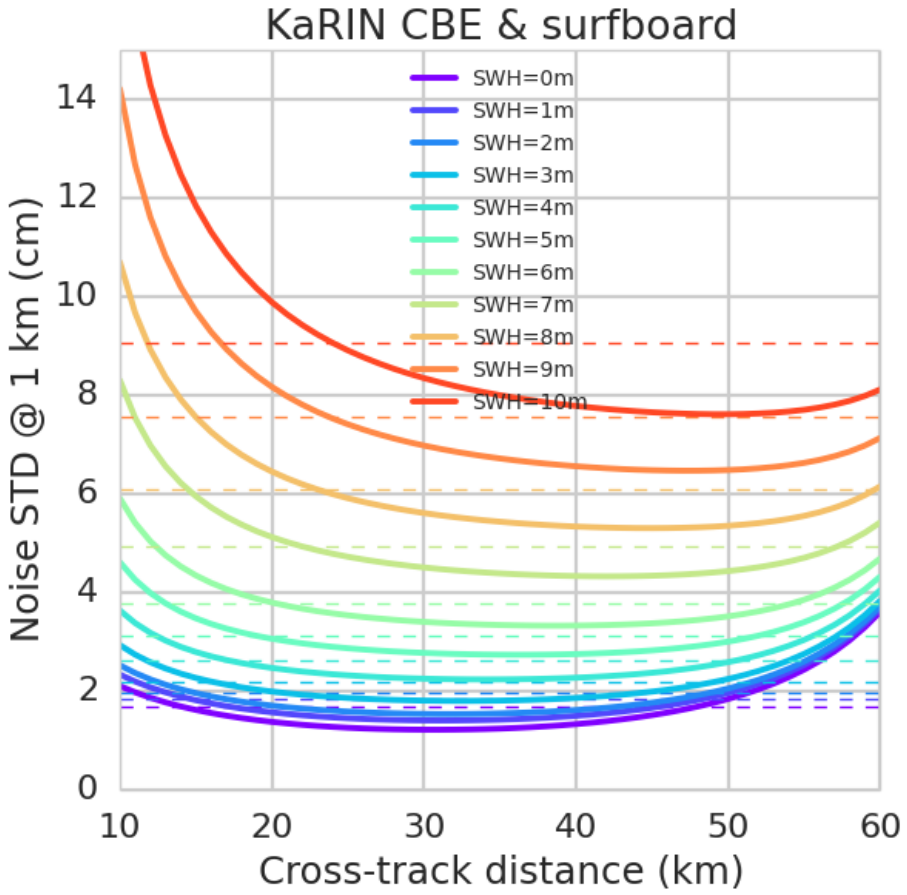


(Ubelmann et al., 2017)

2 km or 500 m trade-off: noise & posting

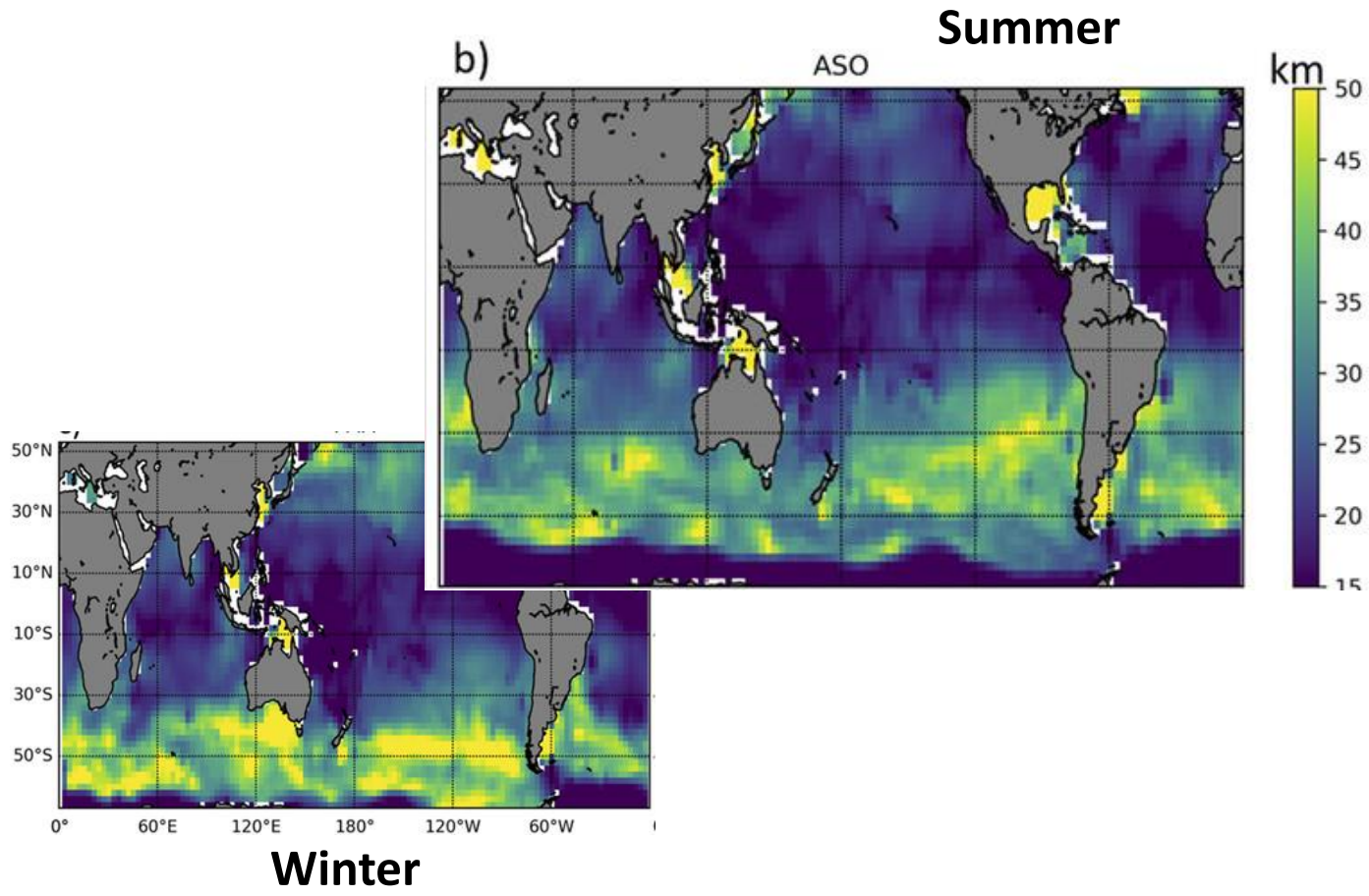


Noise is modulated by waves and higher on each side



(Dibarboure et al, WISA URD, 2017)

Observability from SWOT (i.e. wavelength where SNR=1)



(Wang et al, JAOT, 2019)

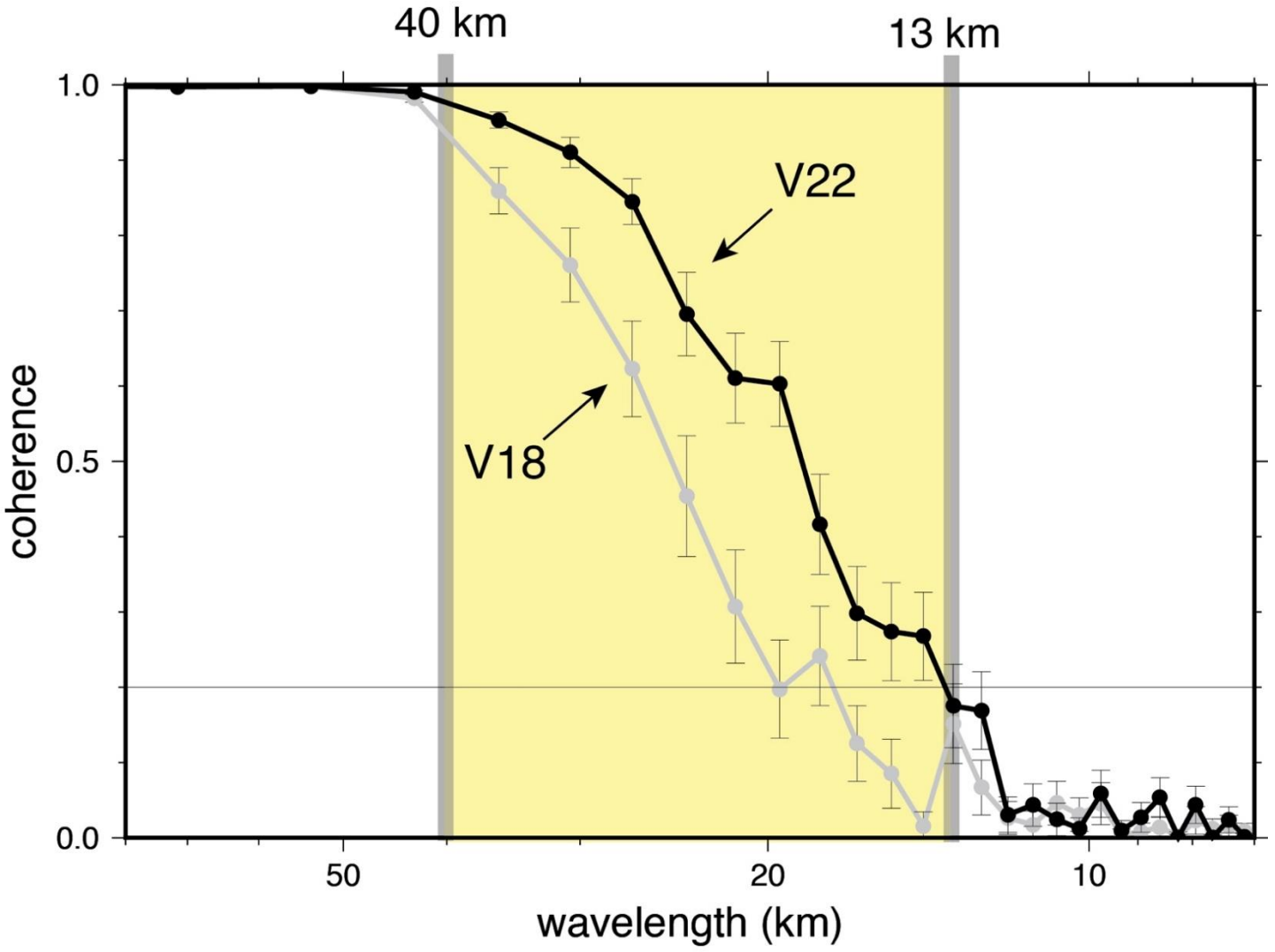
MSS and Geoid

Not an error per se for the SSH

Very important in practice for
SSH *anomalies*

Might be relevant for some in-situ CalVal
in regions where the MSS is not flat

spectral comparisons with in-situ data in the Gulf of Mexico



(D.Sandwell, SWOT SDT meeting, 2015)

Ongoing work: wet troposphere and SSB

Wet tropo algorithms and uncertainty not yet available

- Very important: main error from 50 to 200 km
- Main sources: noise and 20 km resolution of radiometer + swath interpolator
- Wet Tropo error has an upper bound (JPL D-79084, Ubelmann et al 2014)
- Actual error TBD once the radiometer ATBD is available (ongoing work)

SSB has multiple layers of complexity

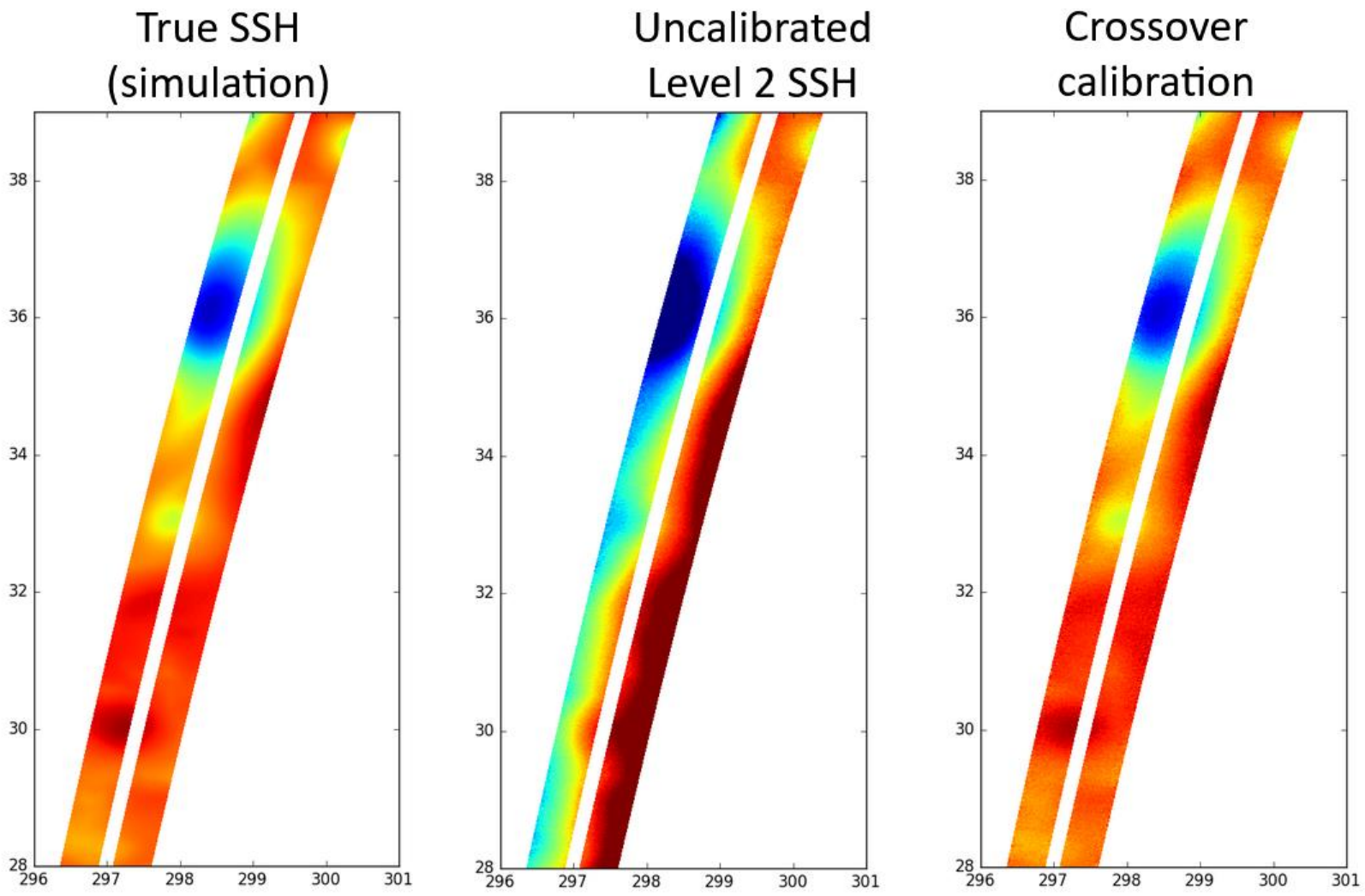
- Some are simple and known from AltiKa (model used for SWOT launch)
- Other are more complex and SWOT specific (swath varying, Hs from KaRIn)
- Current SSB correction strategy is a placeholder to be updated with flight data
- Research-oriented OBP parameters currently not exploited by the Project (ST help needed)

Systematic errors and roll above 1000 km

These signals are irrelevant for the Project error budget (defined up to 1000 km only) but important in practice for oceanographers (could be tens of cm or more)

The cross-over calibration (XCAL) processor is designed to meet hydrology requirements (not needed for ocean reqs)

The XCAL correction **<u>is applied</u>** in SSHA products to reduce large scale biases and skewed images (residual : 2 to 3 cm)



(Ubelmann & Dibarboure, AGU 2016)

Documentation and links

Entry points

- AVISO: https://www.aviso.altimetry.fr/swot/
- 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 samples: https://podaac.jpl.nasa.gov/SWOT?tab=datasets&discipline=ocean&sections=about%2Bresources
- Global 1 year SWOT simulations from MITgcm, eNATL and GLORYS models (CNES cloud)
- Pre-SWOT MITgcm subset for AdAC zones (PODAAC cloud)
- Science a.k.a Portable simulator: available on GIT hub (talk from Lucile Gaultier)
- Small scenes from very realistic simulators (NASA/JPL & CNES/CLS for Project, F.Nougier for ST)

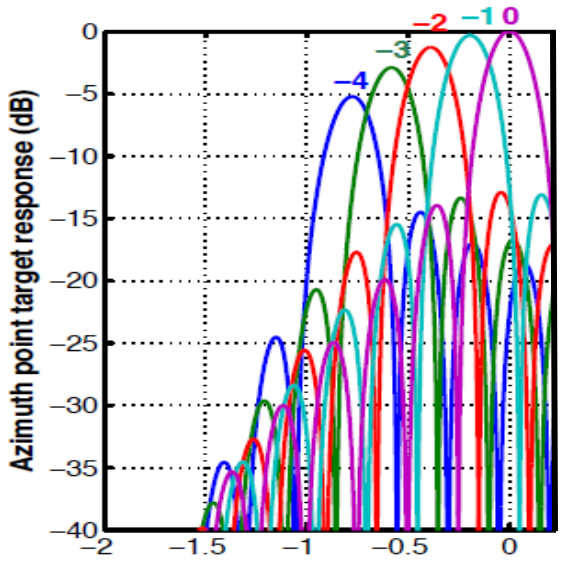
Ocean ST survey for better data sharing

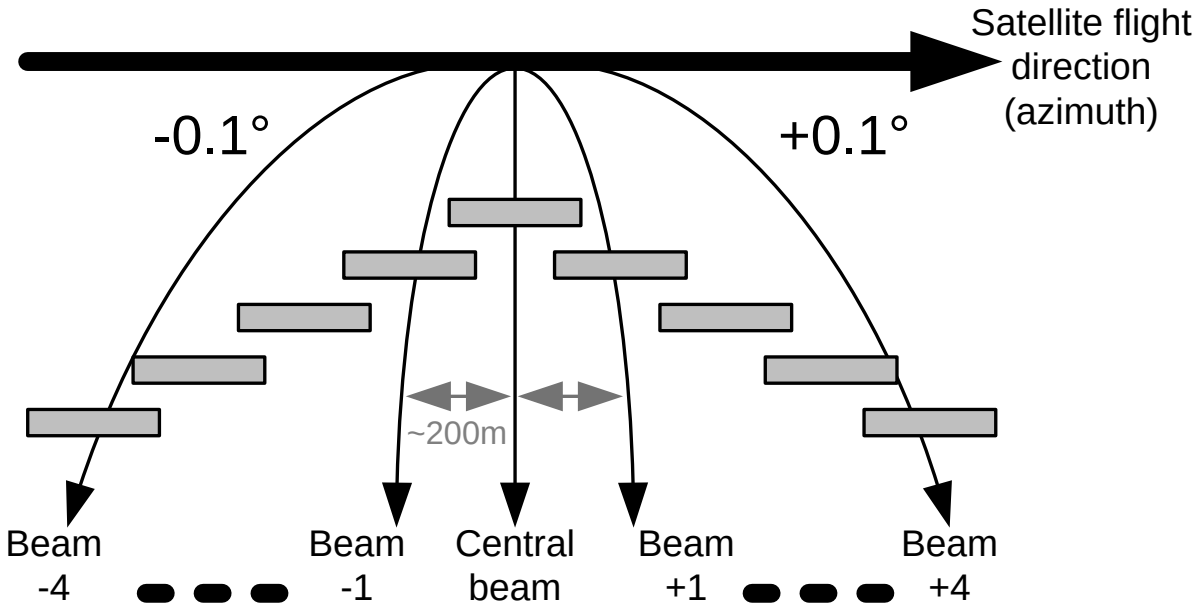
https://docs.google.com/forms/d/e/1FAIpQLSd08hsiIgNvlHy-iwQfHTReZwZc5kmLrGBlLD-AajN6RrRS4g/viewform?usp=sf_link

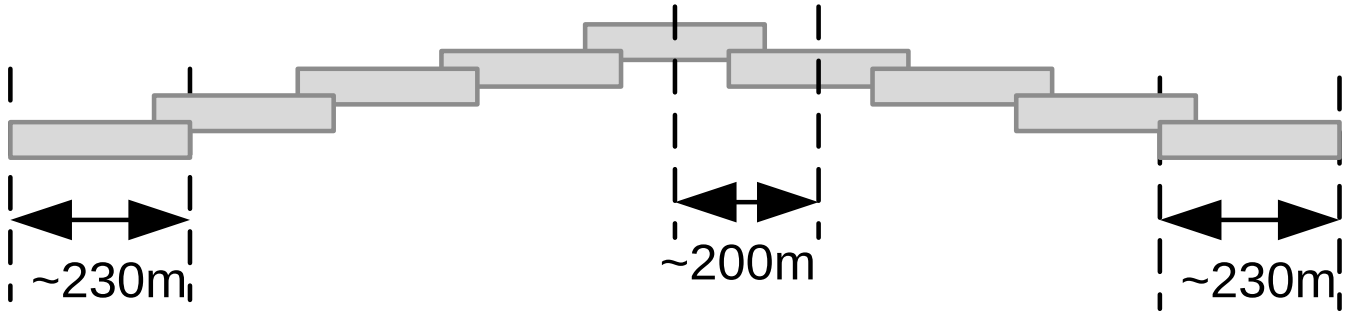
Thank you for your attention

Backup slides

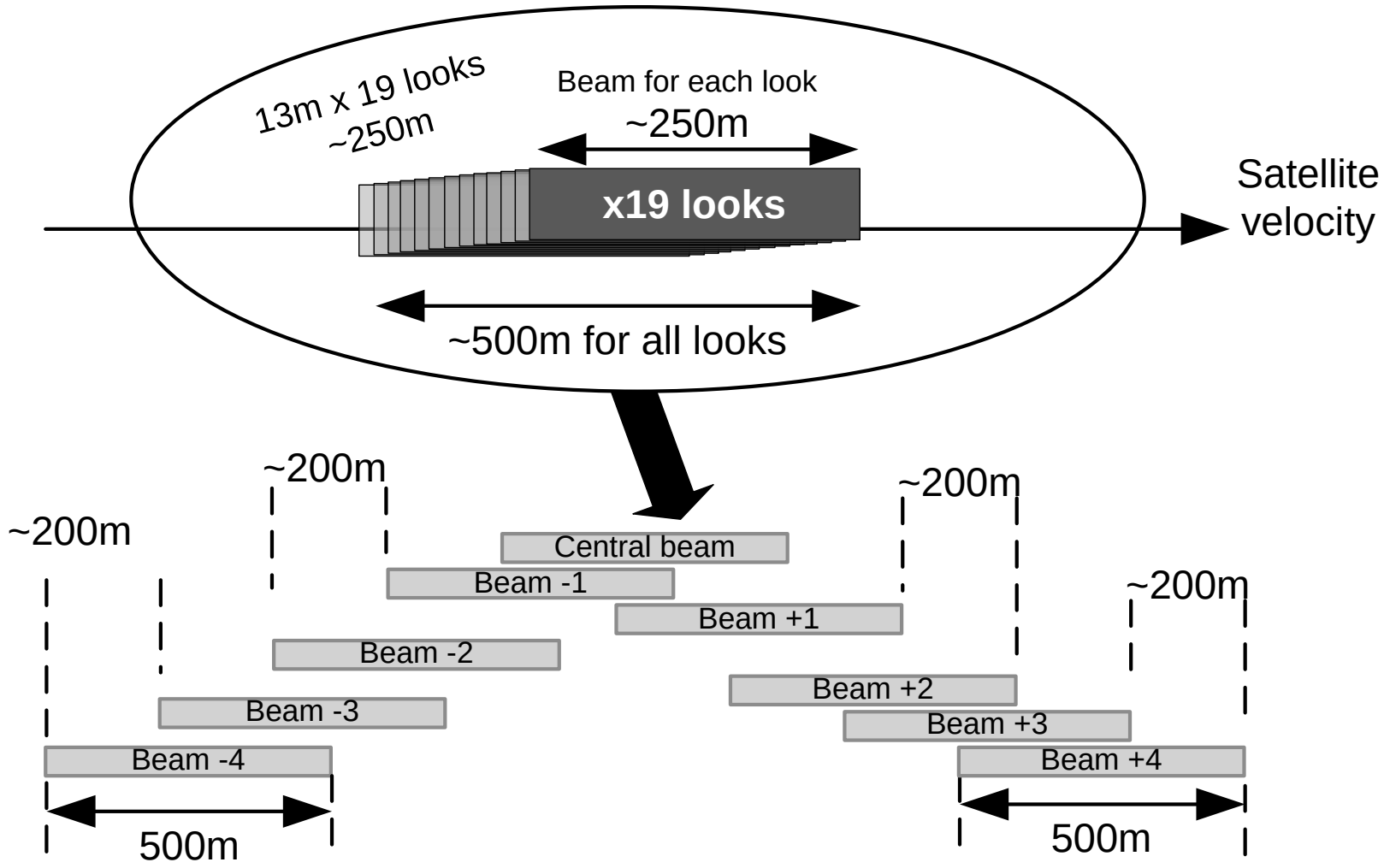
Azimuth SAR processing





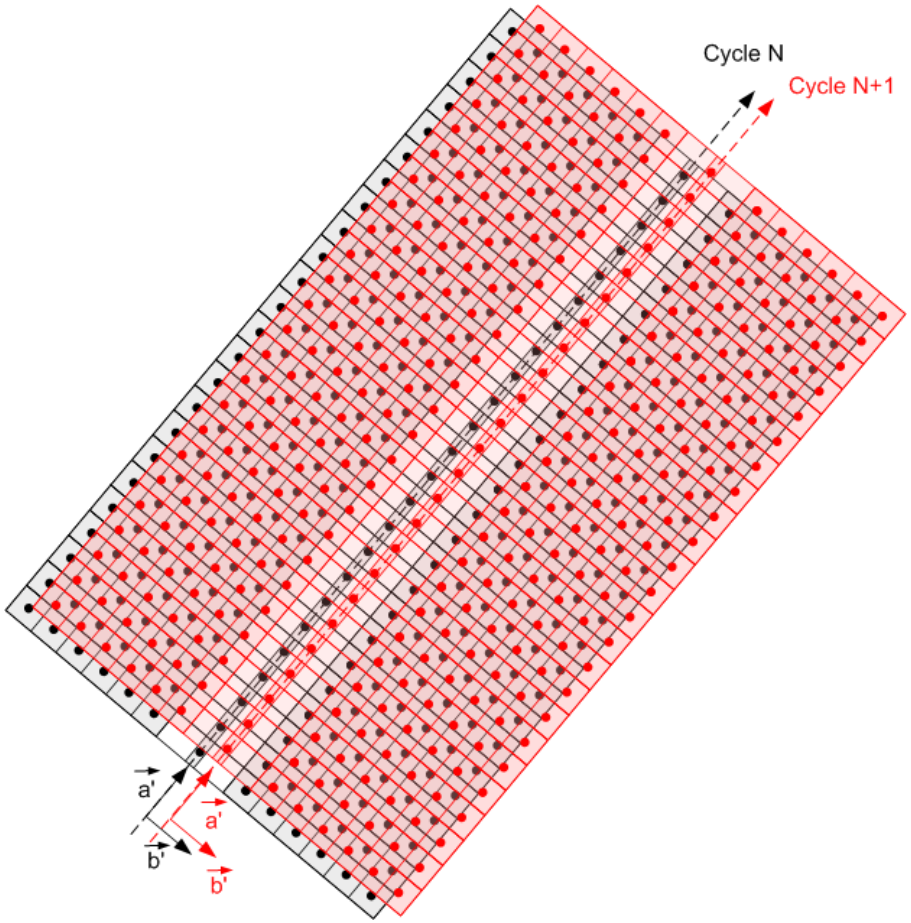


OBP output: 500-m pixels x 9 beams



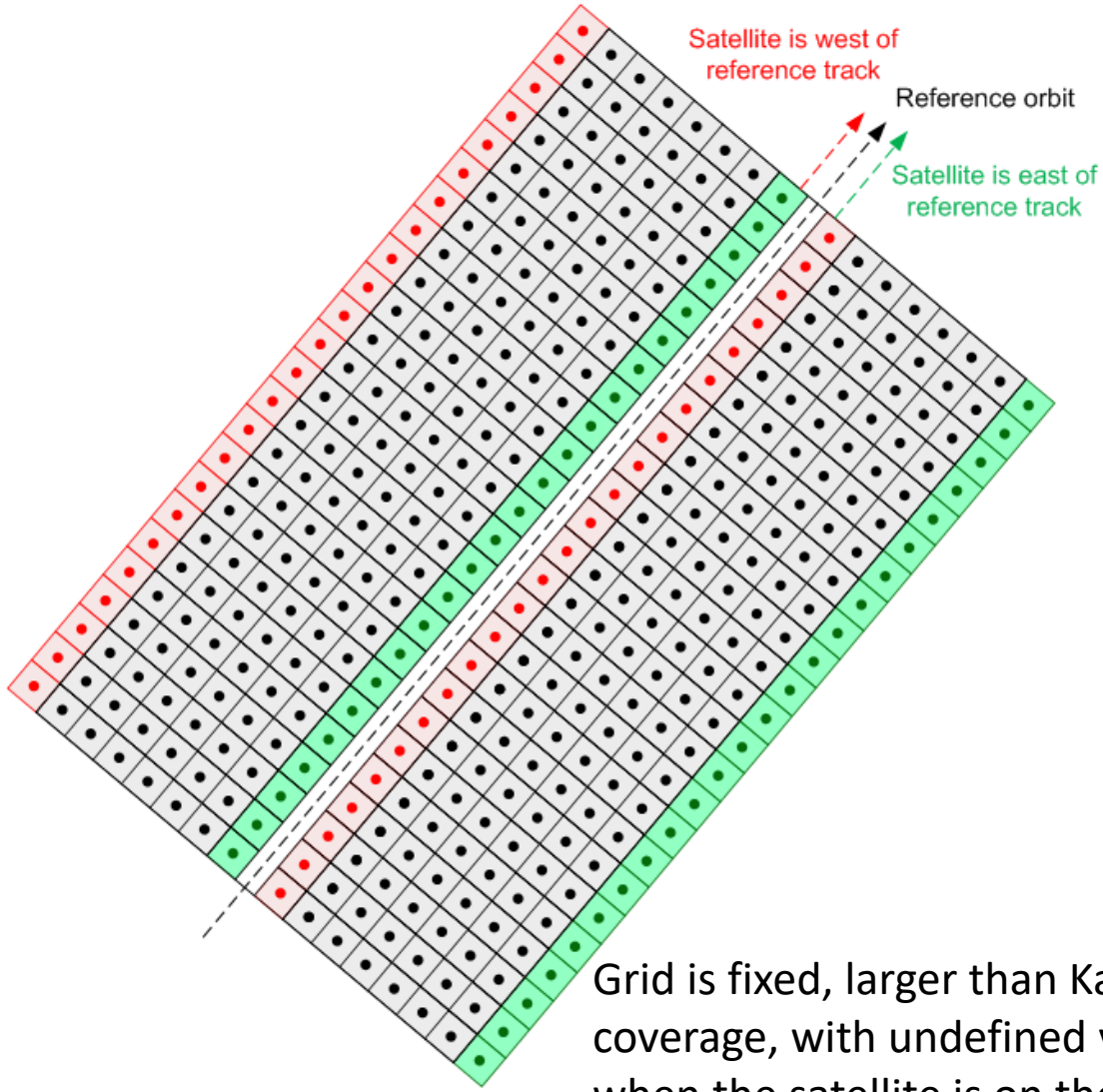
- The 1 km onboard product is built by average a large number of 250 pixels
- In practice, the azimuth averaging uses a larger window (~1km) with Blackman-Harris weights that yield the same number of looks

Swath-oriented native grid (L2A)



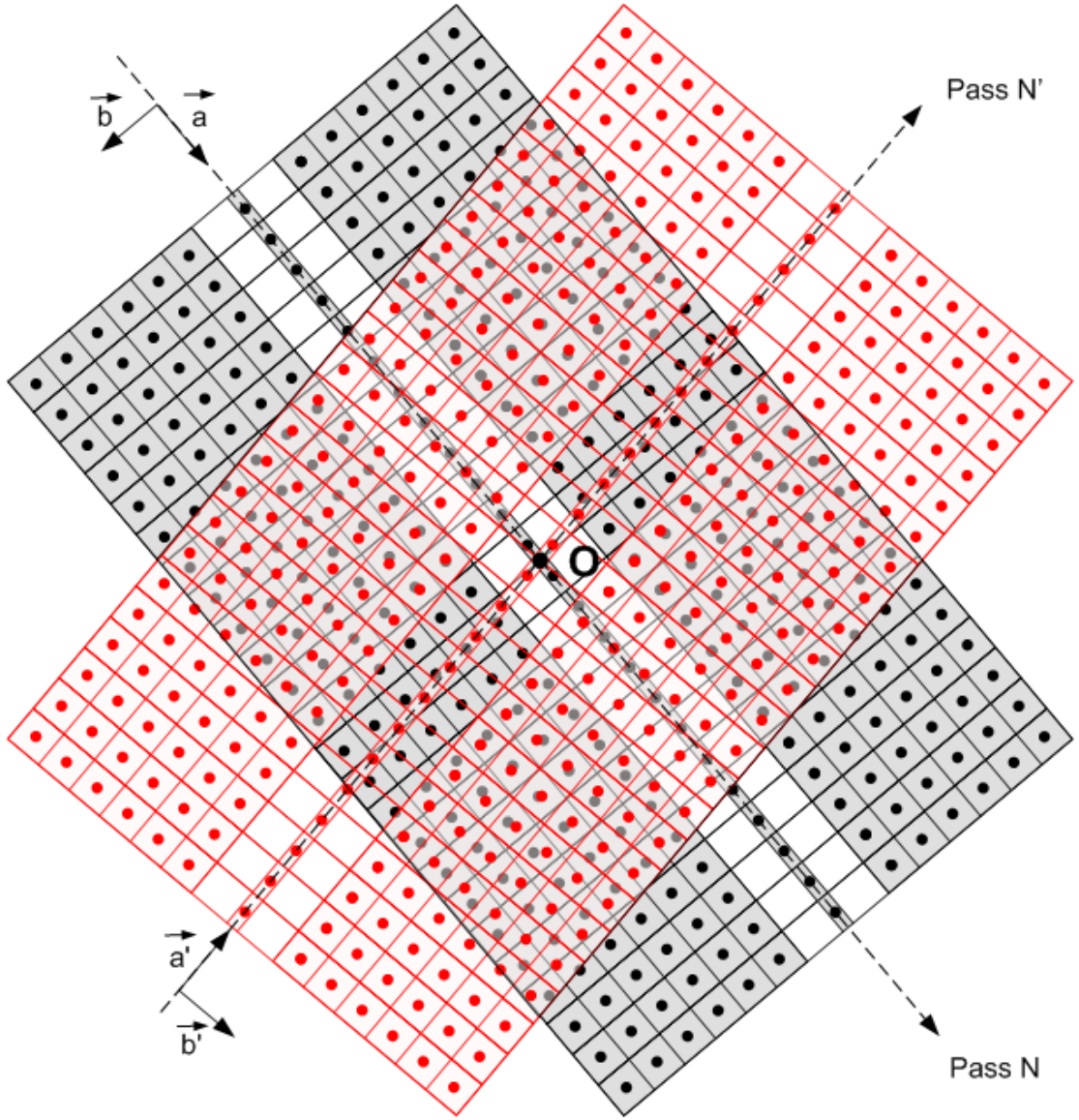
Grid moves with satellite position for each cycle

Swath-oriented fixed grid (L2B)



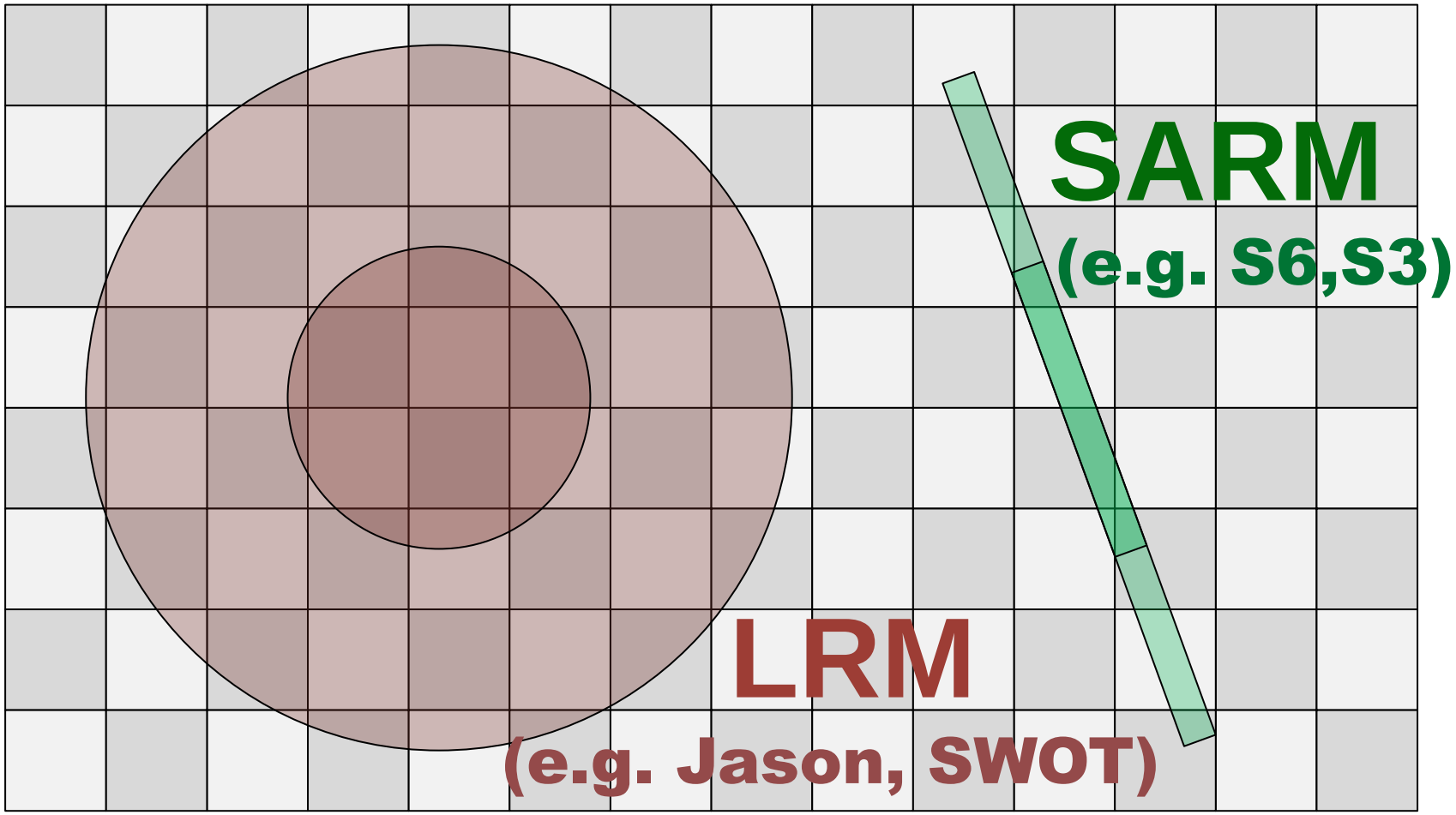
Grid is fixed, larger than KaRIn coverage, with undefined values when the satellite is on the other side

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



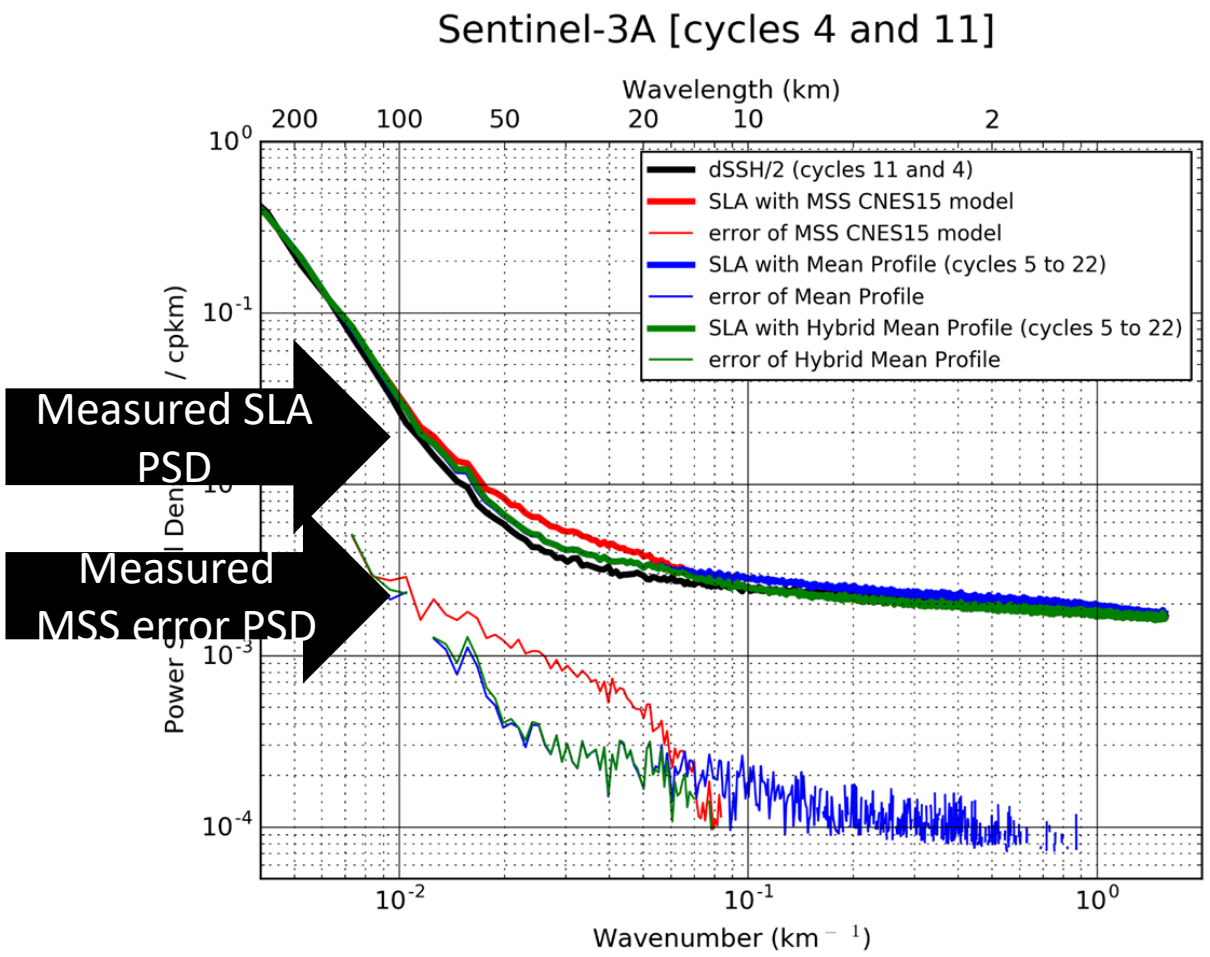
KaRIn products

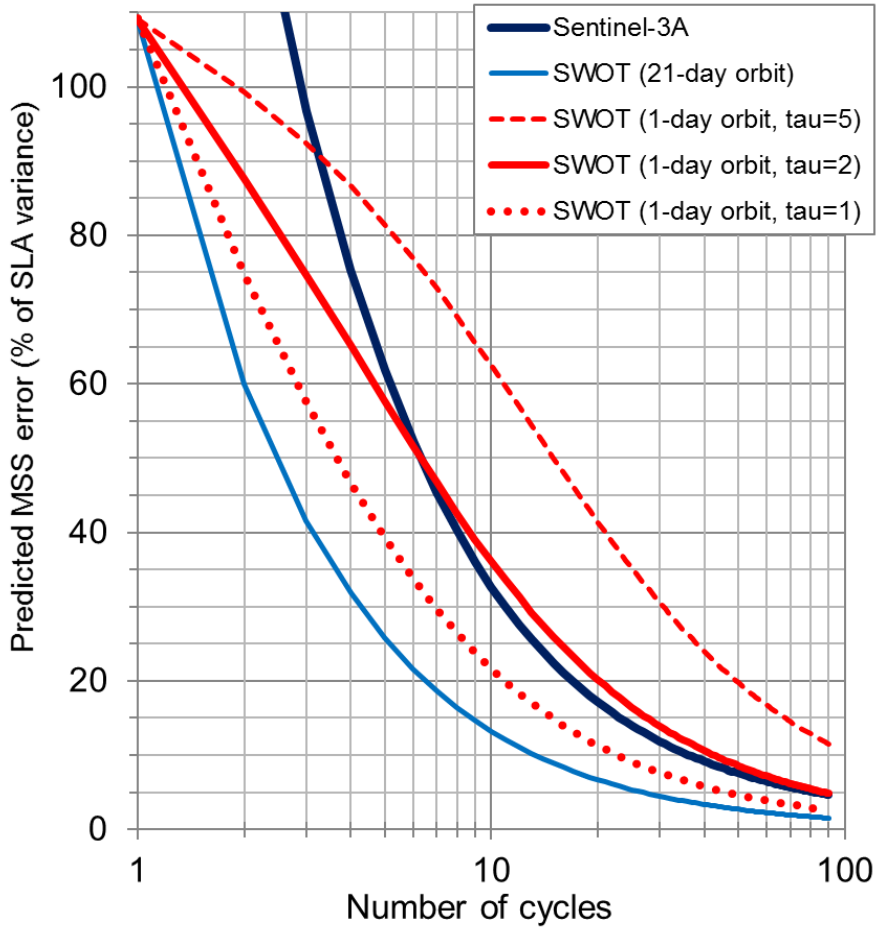
- 20 km (radiometer)
- 2 km
- 500 m
  (posted at 250 m)
- 250 m (σ_0 only)

Nadir products

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

MSS error: current models and SWOT-era





(Dibarboure et al, 2018)

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

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**