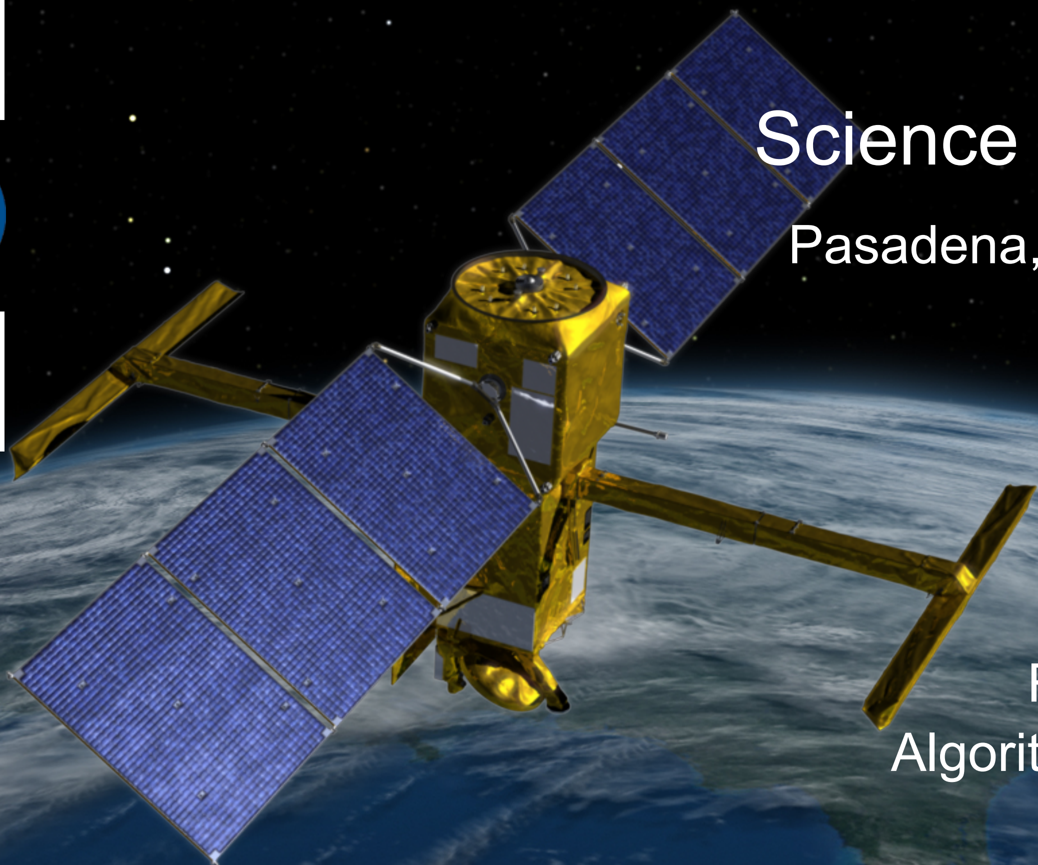
Surface Water and Ocean Topography (SWOT) Mission

Science Team Meeting

Pasadena, June 13-16, 2016



Algorithms

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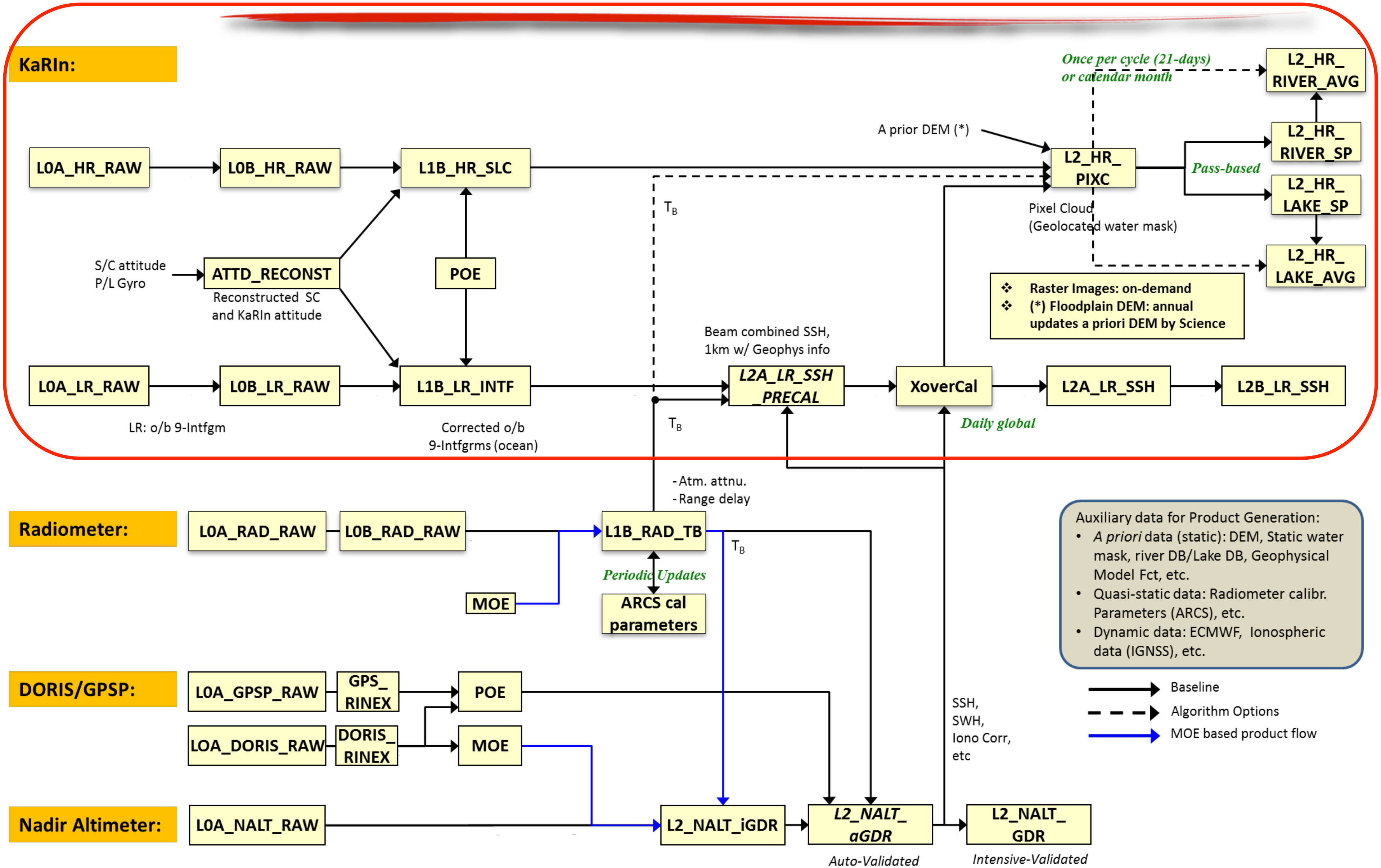
On behalf of the Algorithm Development Team

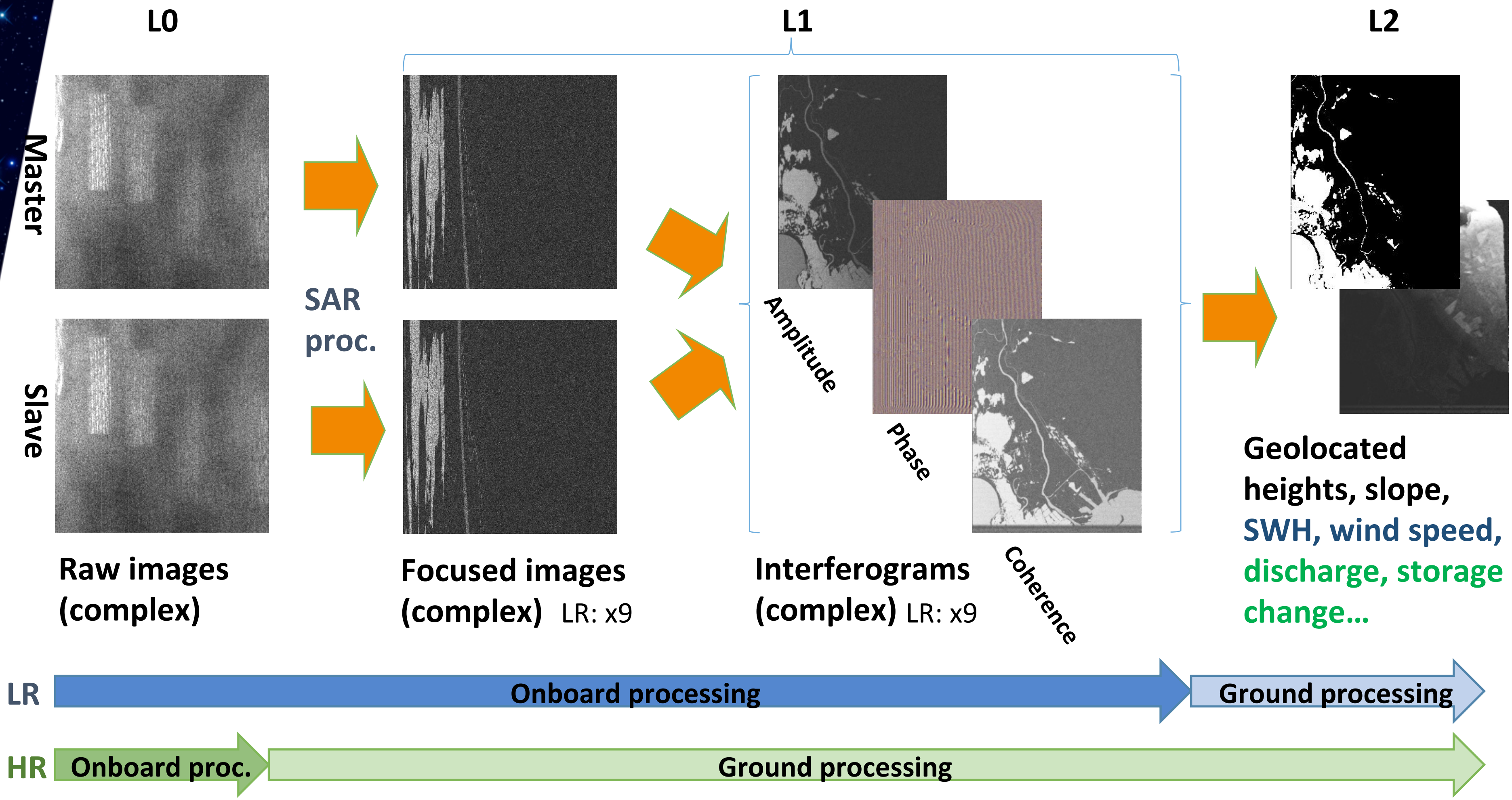
SWOT DocuShare Collection: https://charlie-lib.jpl.nasa.gov/docushare/xxx

SWOT Science Product Flow

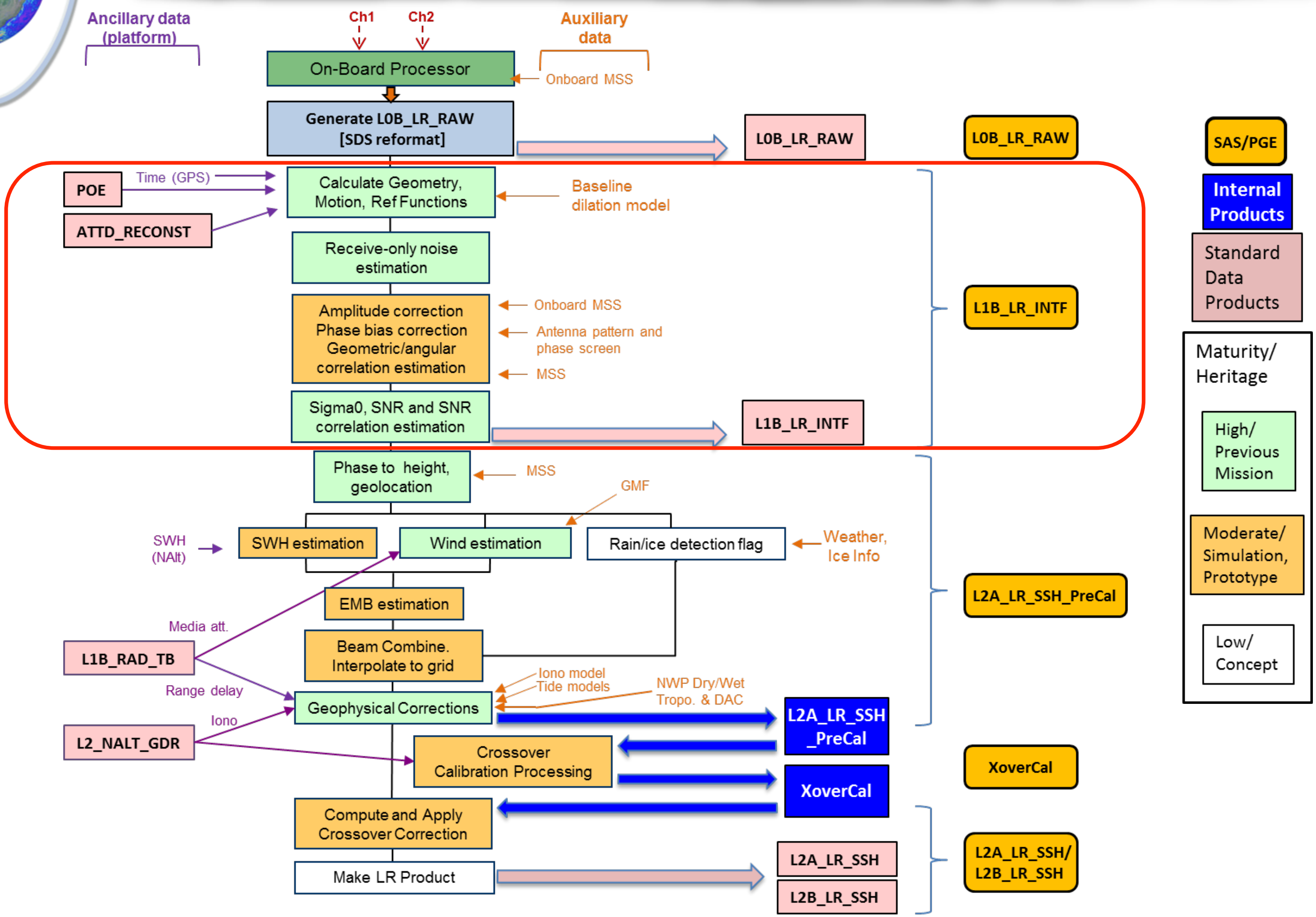


KaRIn LR and HR Processing: Onboard vs. Ground

- KaRIn/SWOT Processing and Product Levels (illustrated with HR images below)

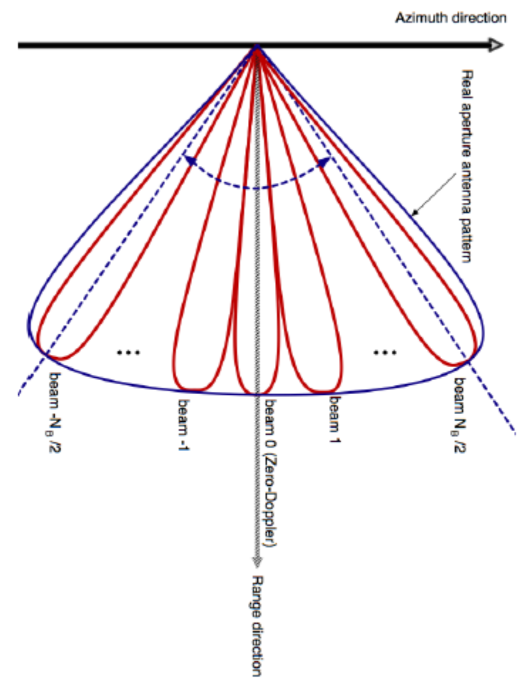


KaRIn LR Ground Processing Flow Diagram



Starting Point for LR Ground Processing

- OBP downlinked inputs (for each swath, left and right):
  - 9 complex interferograms, 500m resolution @ 250m posting
  - Per channel (left and right antenna):
    - 9 power SAR images, 500m@250m
    - Noise and calibration measurements
    - Doppler centroid estimate

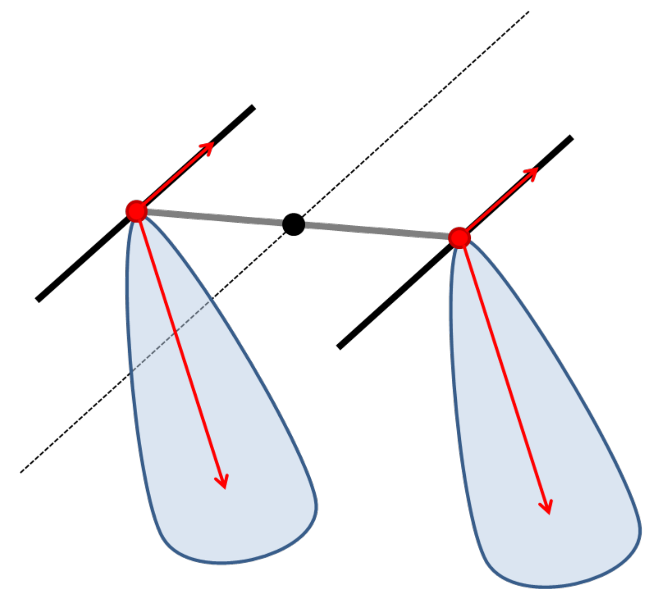


- Additional downlinked mitigation inputs:
  - 250m@250 m power and power variance
  - Wave spectra
  - Doppler centroid image

- Ancillary and auxiliary data

Calculate Geometry, Motion, Ref. Functions

- Determine the precise position and velocity of the phase center of each of the two antennas, as well as their orientation (antenna lobes), as a function of time



- Input:
  - Orbit of the flight system reference center
  - Attitude of the platform and the baseline
  - Flight system and baseline geometry (mechanical) information, including baseline dilatation model

Amplitude Correction, SNR and σ_0

- Receive-only noise *n* measured regularly, averaged.
- Amplitude correction computed for each power image:

$$A_{corr} = \frac{(4\pi)^3 R^4}{P_{tx} G_{tx} G_{rx} \lambda^2 A_{rc}}$$

  - Requires knowledge of range, transmitted power, antenna gains, wavelength, range cell size

- SNR and σ_0 (normalized radar cross section, NRCS) computed based on the SAR power images, the receive-only noise power and the amplitude correction:

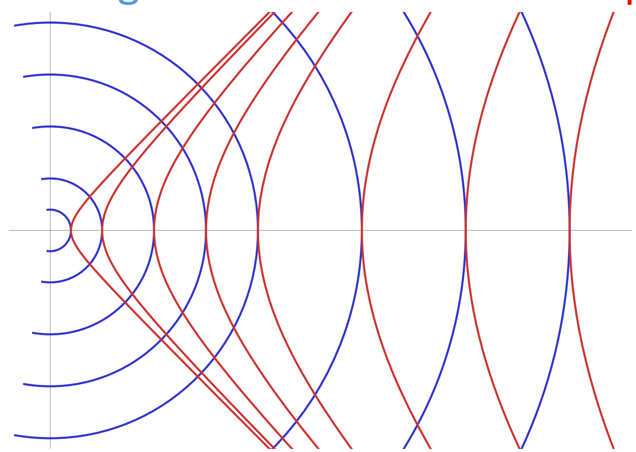
$$SNR^{(J)} = \frac{P_{rx}^{(J)} - \bar{n}^{(J)}}{\bar{n}^{(J)}}$$

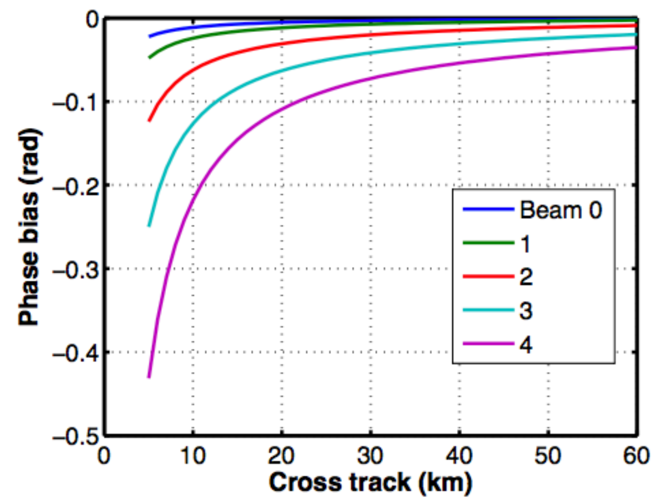
$$\sigma_{0,uncorr}^{(J)} = A_{corr}^{(J)} \cdot (P_{rx}^{(J)} - \bar{n}^{(J)})$$

Phase Bias Correction

- The fact that the iso-interferometric-phase lines and the iso-range lines are not aligned, creates a systematic phase bias.

Iso-range vs. Iso-interferometric-phase





- This phase bias can be compensated for each beam based on knowledge of topography, backscattering (σ_0 contrast), antenna pattern, attitude…
- Phase bias equation and further details in the OBP ATBD

Noise, Geometric/Angular Correlation Estimation

- Total correlation (coherence) measured from interferogram

$$\gamma^{(J)} = \gamma_n^{(J)} \gamma_{\varphi,g}^{(J)} \gamma_{vol}^{(J)}$$

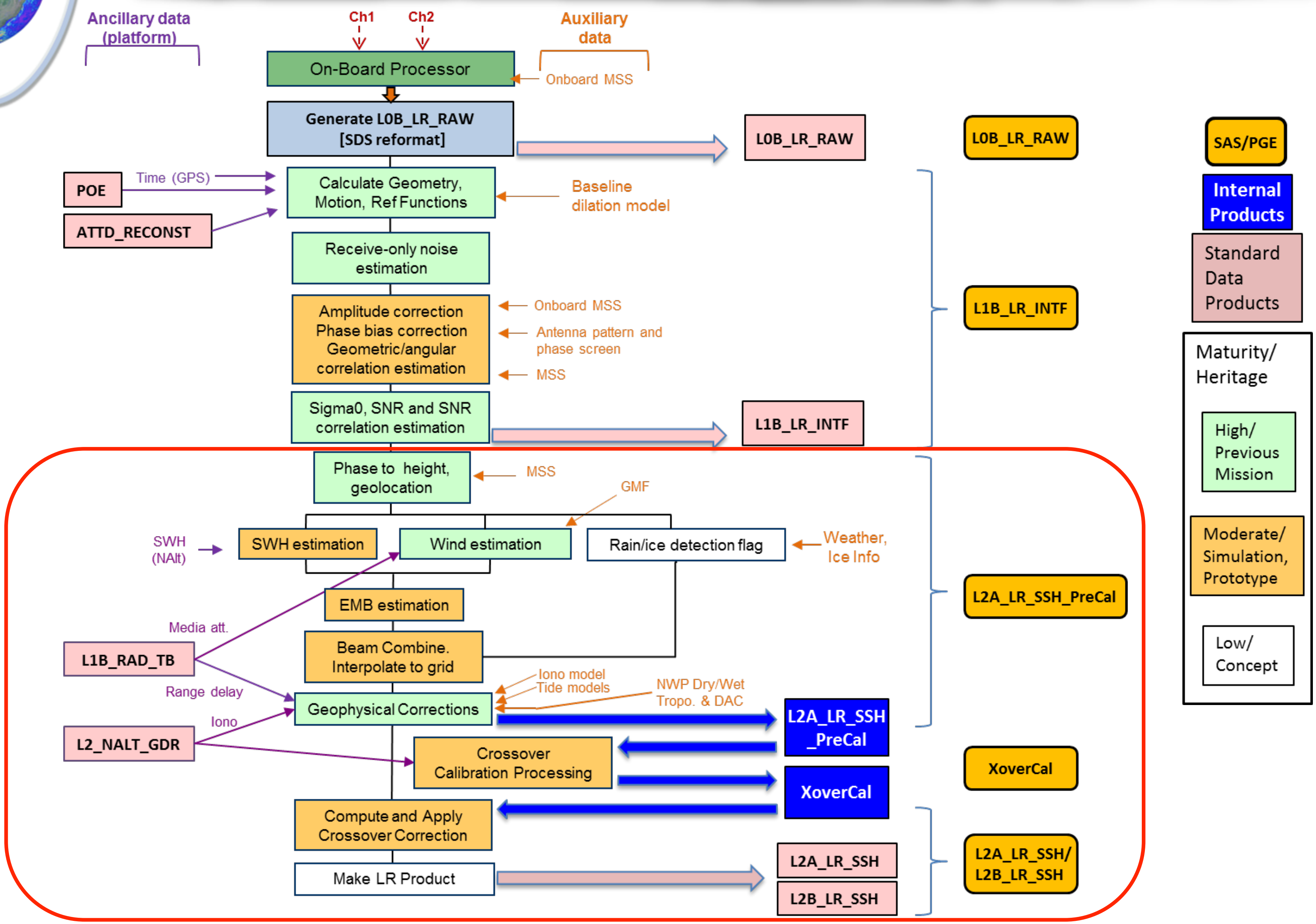
noise angular/geometric volume

- Noise correlation estimated directly from the SNR of the two channels

$$\gamma_N^{(J)} = \frac{1}{\sqrt{\left(1 + \frac{1}{SNR_1^{(J)}}\right)\left(1 + \frac{1}{SNR_2^{(J)}}\right)}}$$

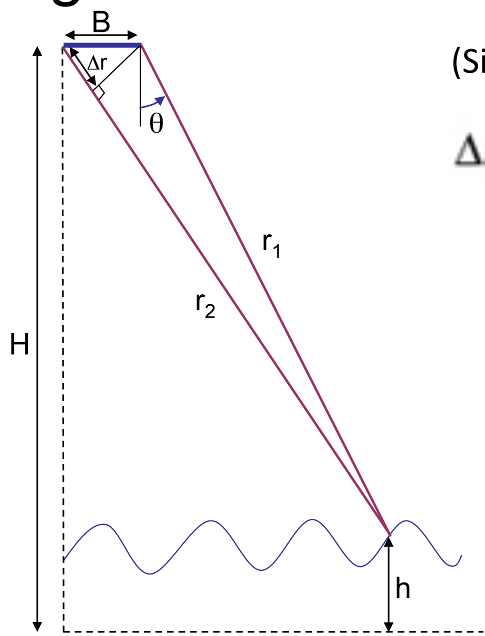
- Geometric/angular loss of correlation
  - pixels are not points but surfaces, so that the interferometric phase difference varies throughout the resolution cell,
  - misalignment of iso-range and iso-phase (cfr. phase bias).
  - angular correlation equation specific to SWOT OBP algorithm

KaRIn LR Ground Processing Flow Diagram



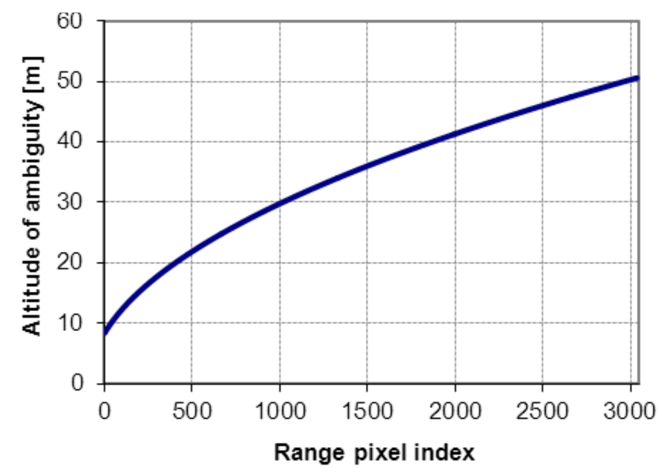
Phase-to-Height, Geolocation

- Basic principle: invert phase difference into geolocated heights based on reference surface.



(Simplified illustration and equations)

$$\Delta r = r_2 - r_1 = B\sin(\theta)$$
$$\Delta r = \frac{\lambda}{2\pi}\Phi$$
$$\Rightarrow$$
$$\theta = \arcsin\left(\frac{\Phi}{B}\frac{\lambda}{2\pi}\right)$$
$$h = H - r\cos(\theta)$$



- Textbook inversion based on direct geocoding equations using MSS as reference (+ tide model?)
- Far range unambiguous, near range may require limited phase unwrapping (large unaccounted-for tidal variation)

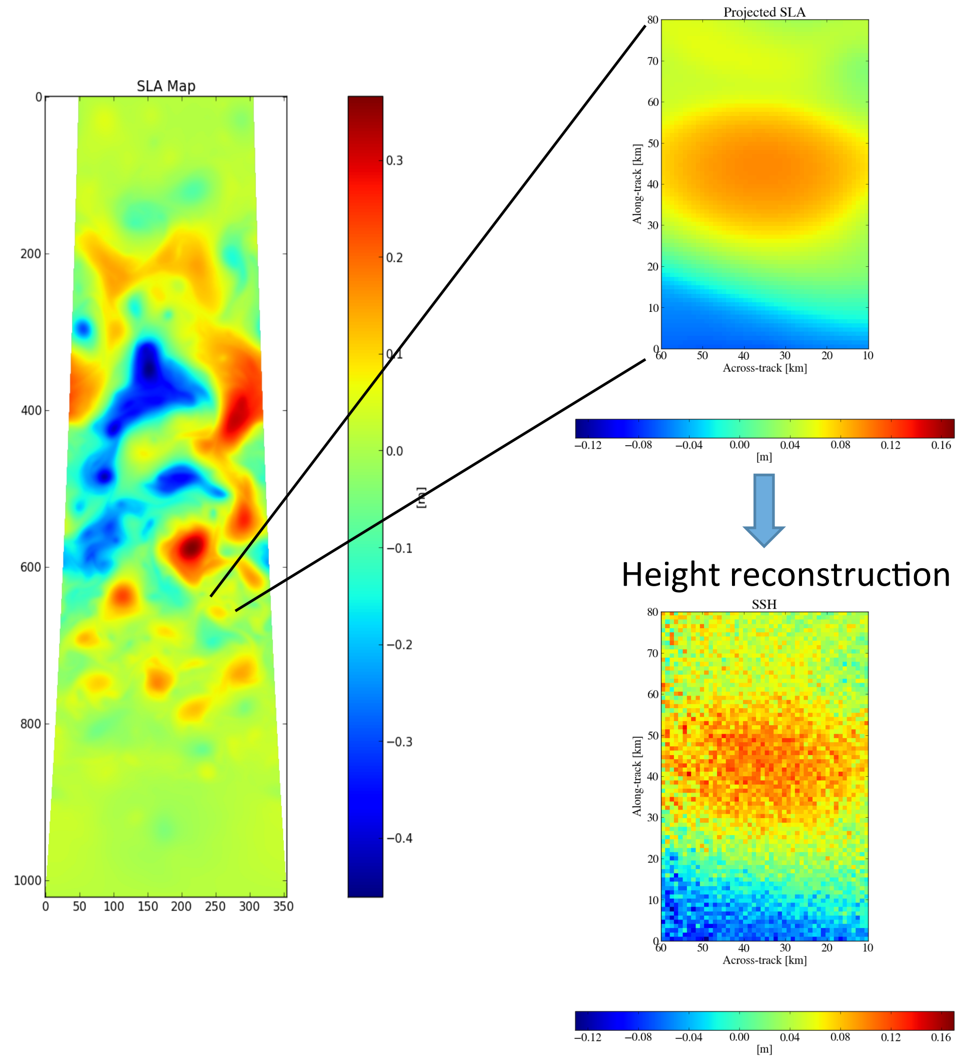
Phase-to-Height, Geolocation

- Illustration of estimated height based on simulated data

- Ocean scene with realistic MSS, SLA and wave field (e.g., SWH=2m).

- Reference surface is the either the MSS alone, or an ellipsoid at some offset from mean elevation of the MSS.

- 10x50 km^2 simulation tested at several resolutions and postings, with real orbit scenario, but perfect attitude knowledge.



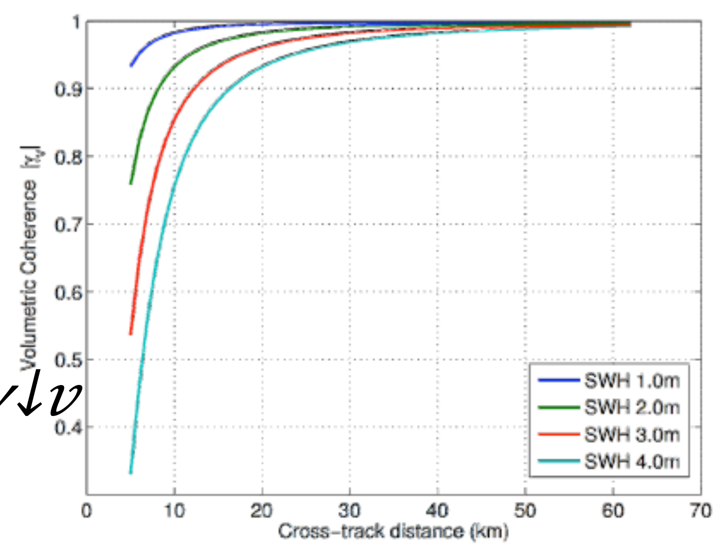
SWH Estimation

- The basic approach for Significant Wave Height estimation is inversion of the volume correlation, computed from the other correlation terms and the measured total correlation (coherence)

$$\gamma = \gamma_N \times \gamma_v \times \gamma_\varphi \quad \Rightarrow \quad \gamma_v = \gamma / \gamma_N \times \gamma_\varphi$$

$$SWH = 4\sqrt{2} / \kappa_z \sqrt{-\ln \gamma_v}$$ where $\kappa_z = kB\cos\theta_0 / r\sin\theta_{i0}$

- Better accuracy can be achieved by assuming the SWH is approximately constant across the swath, and fitting a curve $\gamma_v(\kappa_z, SWH)$ to the estimated γ_v

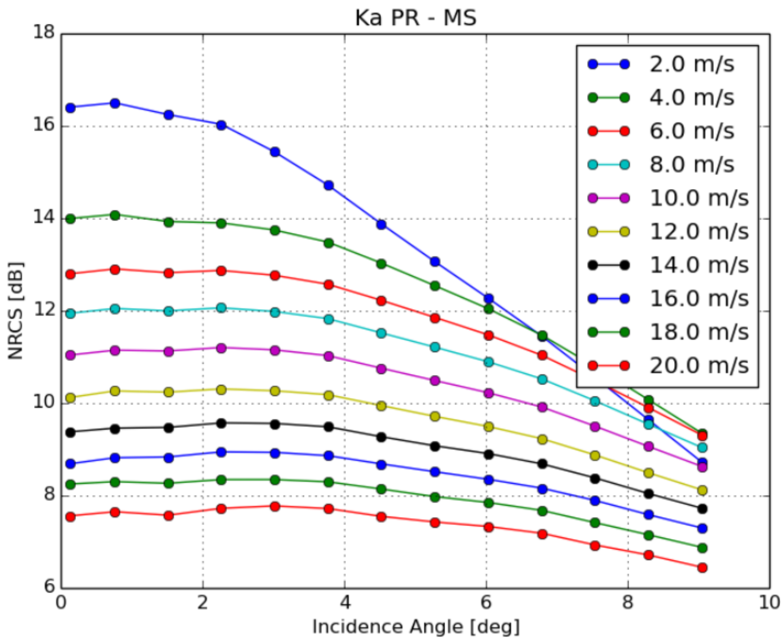


Wind Estimation

- Sea surface wind speed estimation is based on heritage from Jason and SARAL: inversion of NRCS (σ_0)
- Feasibility in Ka-band observed with AltiKa/SARAL and GPM
  - Relies on a model function relating the ocean surface σ_0 to the local near-surface wind speed versus antenna look direction and incidence angle…
  - Pre-launch Geophysical Model Function (GMF) can be built on existing datasets: GPM data analysis show the dependence of Ka-band σ0 to the incidence angle and at different wind conditions

$$\hat{U}_{LS} = \arg\min_{U} \left(\left\| \sigma^0 - GMF(U,\theta) \right\|^2 \right)_{|\theta}$$

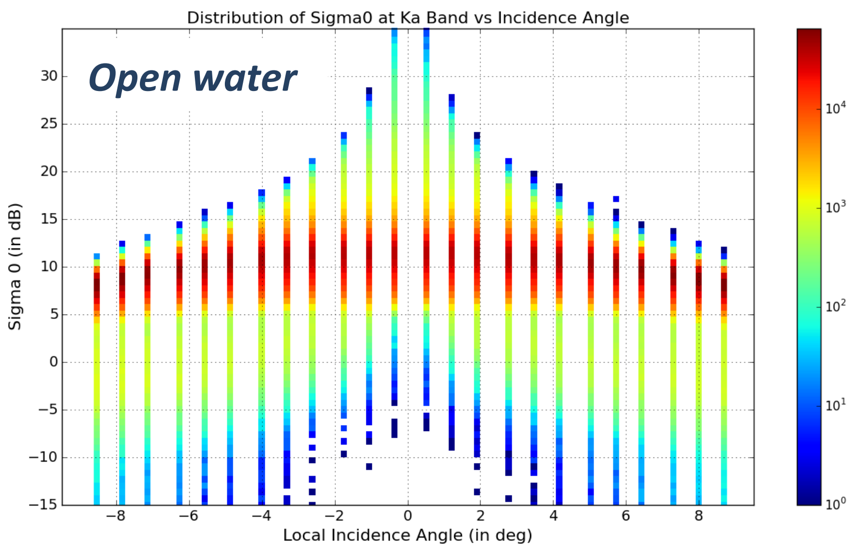
  - More sophisticated approaches are also being studied by Science Team (new parameters in the GMF)

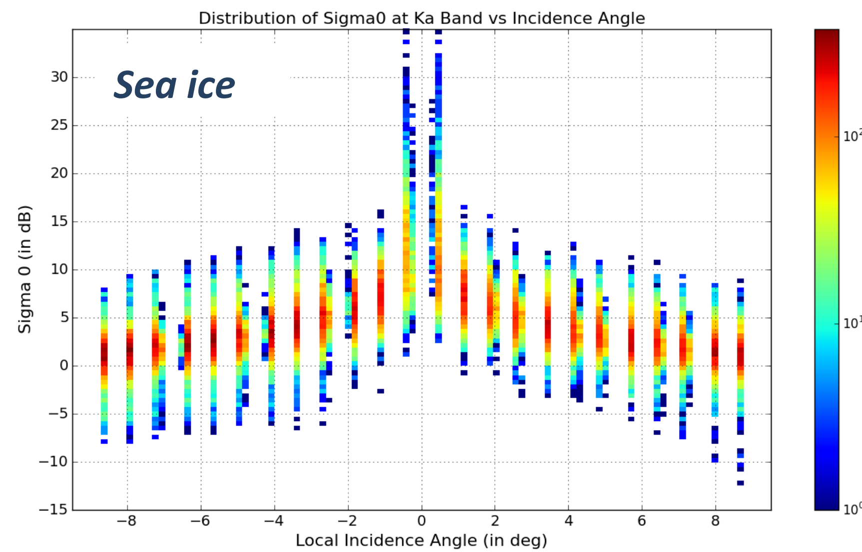


Ka-band σ_0 from GPM mission wrt incidence angle, from Ifremer Science Team members

Rain/Ice Detection Flag

- Both rain attenuation and sea ice are expected to cause significant drops in backscattering (σ_0) and coherence
- Heritage from nadir altimetry. KaRIn algorithms need more work.
- Radiometer, Nadir and KaRIn data can be combined.
- Use of auxiliary data such as *Eumetsat's* OSI-SAF ice concentration
- The high resolution σ_0 uncertainty can be used for outlier flagging





N. Longépé et al. "*The KaRIN off-nadir ice flag can be based on **rapid increases/drops in radar cross-section** (e.g. the GPM Ka-band mission observes on average a +/-10 dB during ocean to ice transitions) that will be visible in the 250-m sigma0 mean and variance.* "

EM Bias Estimation

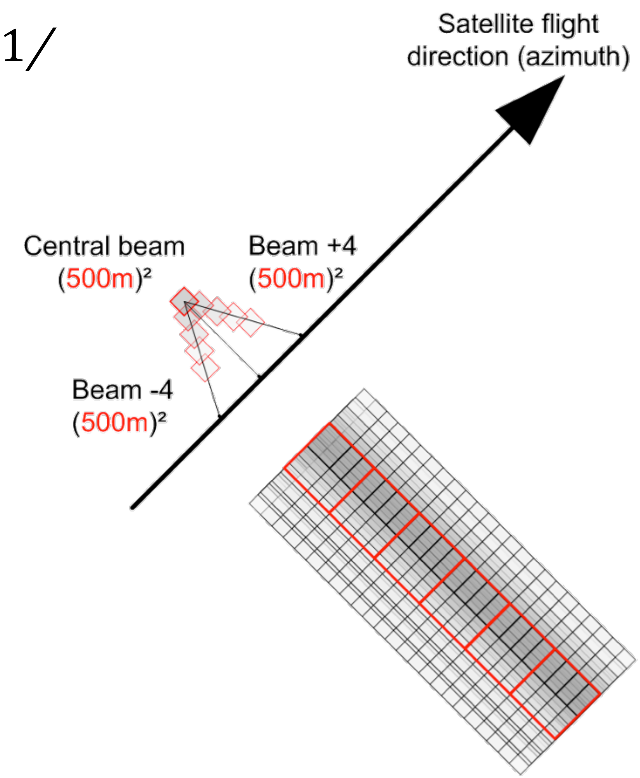
- The electromagnetic (EM) bias is a phenomenon caused by the fact that averaging wave regions with different radar back scatter will bias the height results towards the brighter wave regions (typically, the wave trough).
- This effect is present in traditional altimetry and is usually estimated from cross-over or repeat track data under different SWH conditions, complimented by modeling.
- The AltiKa mission has derived models for the EM bias for Ka band nadir incidence.
  - At this point, this model is the baseline for SWOT corrections.
- For SWOT, additional factors in the EM bias might be caused by changes in incidence angle and/or wave direction and spectrum
  - These points are being addressed pre-launch via direct measurements (AirSWOT) and modeling (France & US)

Beam Combine – Interpolate to Grid

- Input: The 9 beams yield 9 height maps composed of pixels with 500m resolution @ 250m posting, with ~200 m azimuth offset between consecutive beams
- Weighting of the heights according to the height uncertainty of the beams (central beams are less noisy)

$$h = \sum_{i=1}^{N_B} w_i h_i \quad \text{with } w_i = 1/\sigma_{h_i}^{2} \sum_{j=1}^{N_B} \sigma_{h_j}^{-2}$$

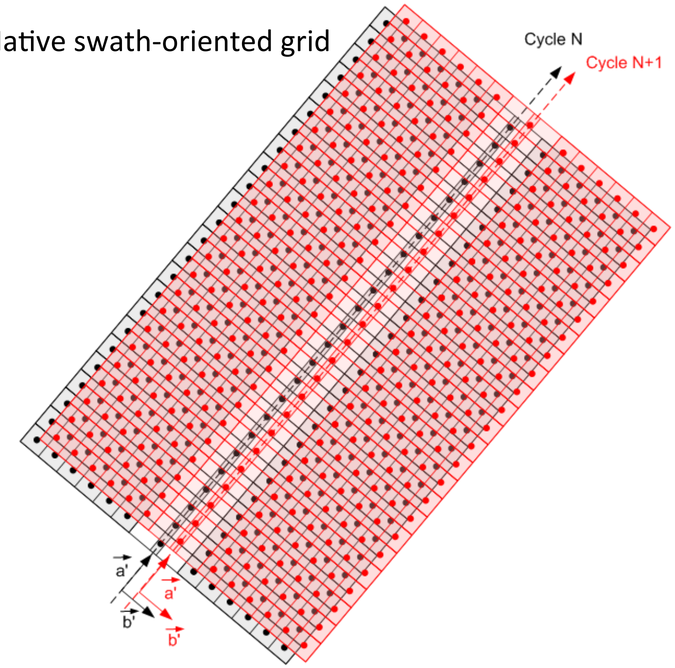
- Combine highly overlapping 500m@250m pixels to create 1 km pixels



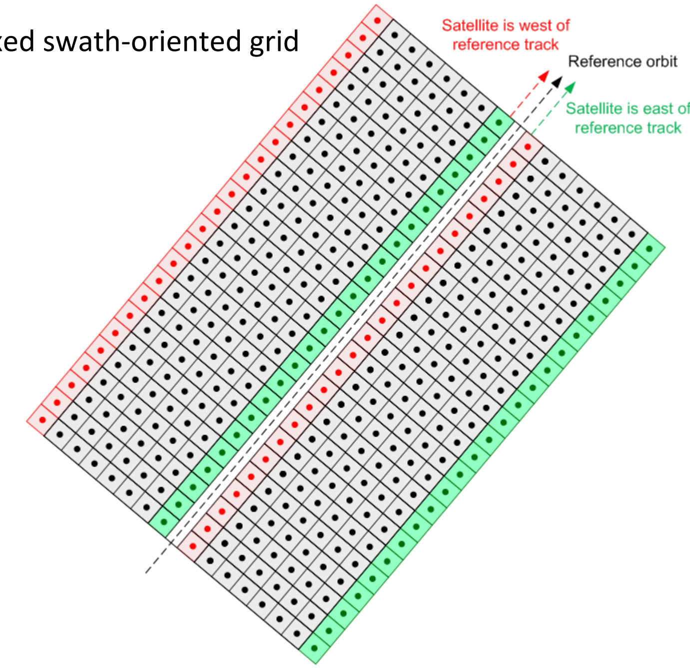
Beam Combine – Interpolate to Grid

- Interpolation to native grid and fixed swath-oriented (or global) grid

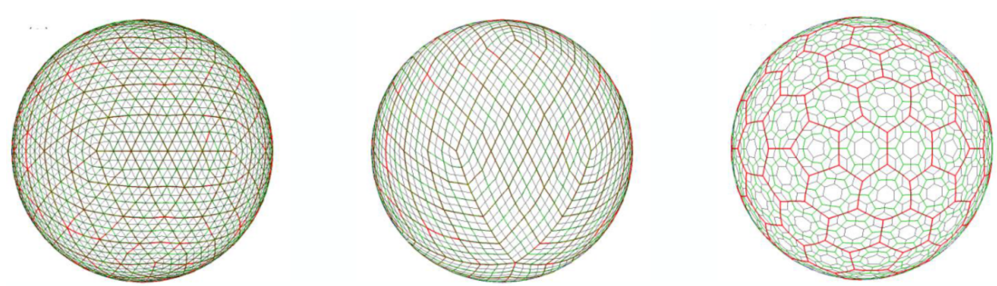
Native swath-oriented grid



Fixed swath-oriented grid

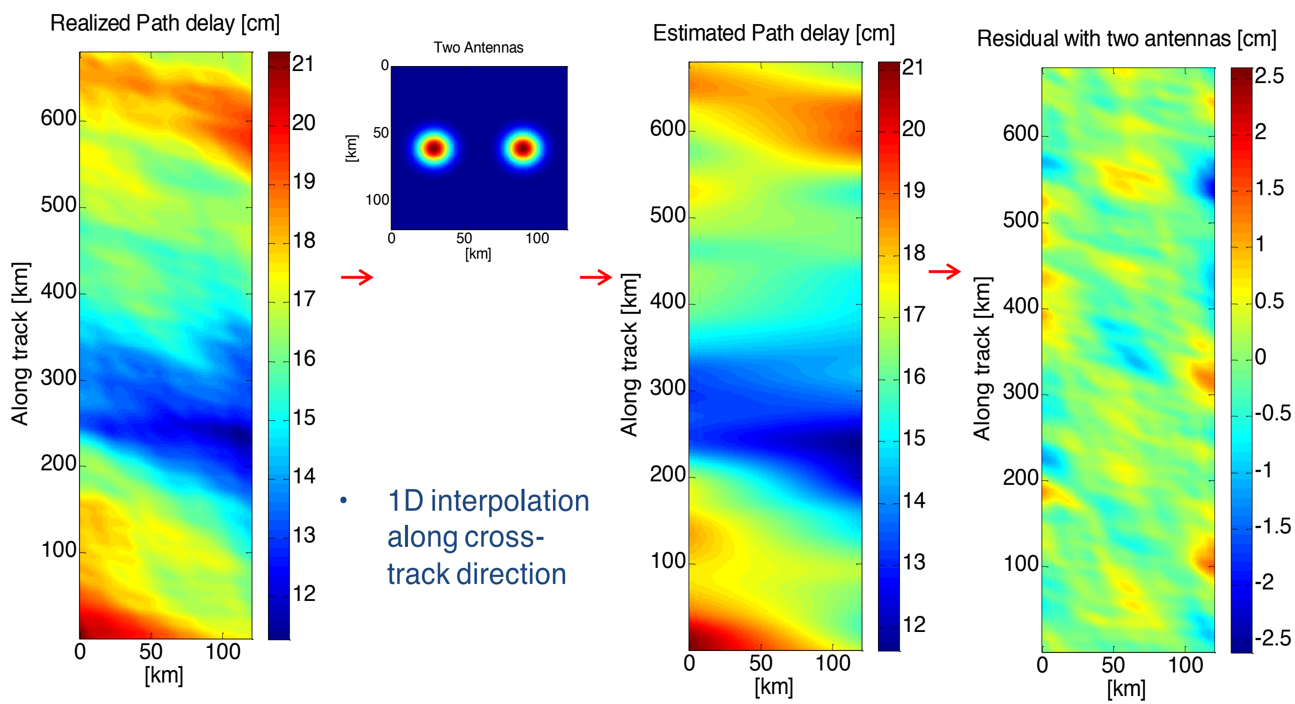


Examples of fixed global grids



Wet Troposphere Correction

- One radiometer measurement in each KaRIn swath
- Current baseline: Jason heritage path delay algorithm and cross-track linear interpolation on each filtered path delay stream to generate swath path delay
- Provides value at nadir as well as cross-track slope



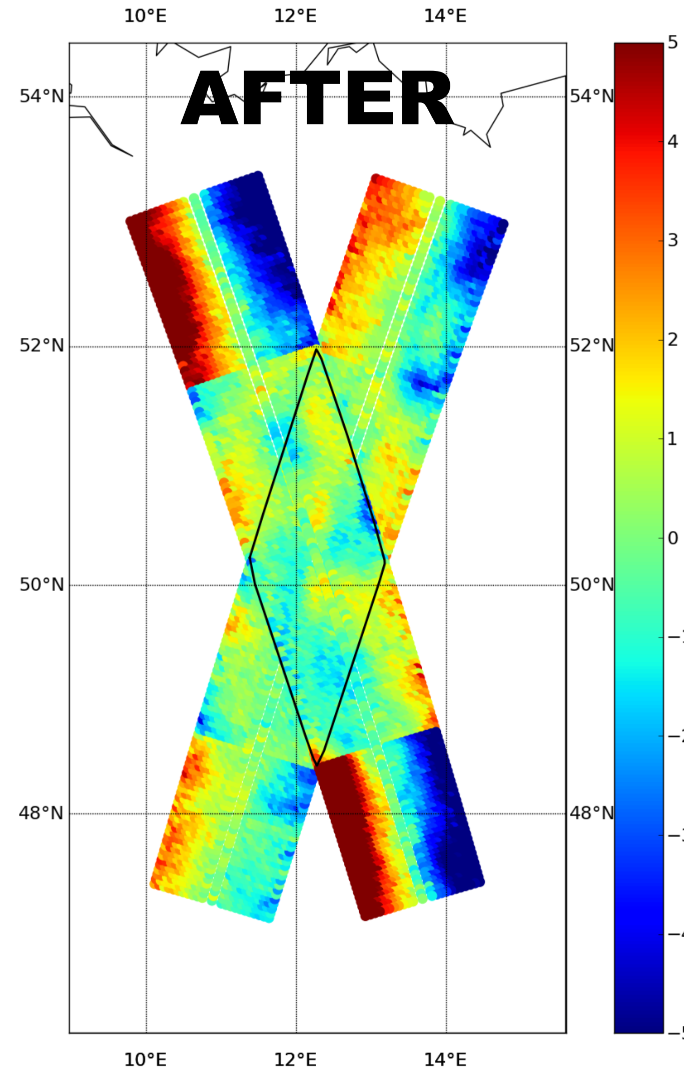
Geophysical Corrections

- Based mostly on heritage from nadir altimetry, legacy systems
  - Dry (and wet) tropospheric delay correction (model-based):
    - Currently based on European ECMWF model
  - Ionosphere:
    - Correction based on JPL GIM (GPS Ionosphere Model) maps
    - Correction from bi-frequency nadir altimeter (Ku/C)
  - Ocean tides:
    - Provided by Science Team, heritage from Jason OSTST
    - Internal tides: important new development; not applied to SSHA
    - Pressure and wind stress input to Dynamic Atmospheric Correction (DAC - "inverse barometer").
  - Pole and land tides :
    - Legacy system, heritage from Jason OSTST.
  - MSS, geoid and MDT
    - International collaboration on new models

- Gather output of L2 processing steps to make pre-calibrated L2A_LR_SSH_PreC product (i.e. without cross-over calibration)

Crossover Calibration

- SWOT ocean (and land) topography is skewed by uncalibrated residual roll.
- For crossovers where both swaths are visible (black diamond), roll is mitigated.
- ~30.000 ocean crossovers every 21 days
- Inland crossovers cannot be used (SNR and topography errors, limited water coverage, layover)
- Interpolation of crossover corrections to obtain height correction for each L2 LR pixel (and phase corrections for each HR pixel).



Example of XOVER diamond and local calibration

Make LR Product

- Update the pre-calibration L2A_LR_SSH_PreC product by adding crossover-correction field.

2D data provided in swath
Latitude, Longitude
Surface type
SSH, σ0, SWH
Associated uncertainties, quality indicators
Ice and rain flags
Corrections (geophysical and calibration)
Geophysical parameters (MSS, tides, …)

2D data provided in swath
Latitude, Longitude
Surface type
SSH, σ0, SWH
Associated uncertainties, quality indicators
Ice and rain flags
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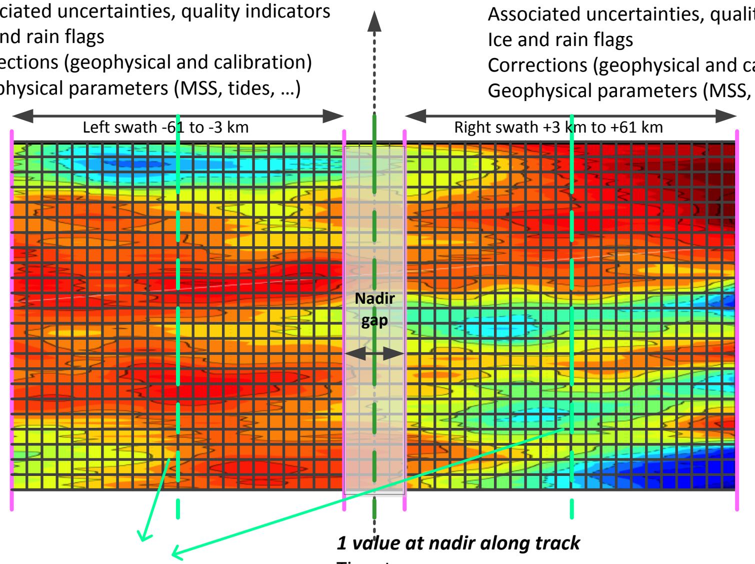
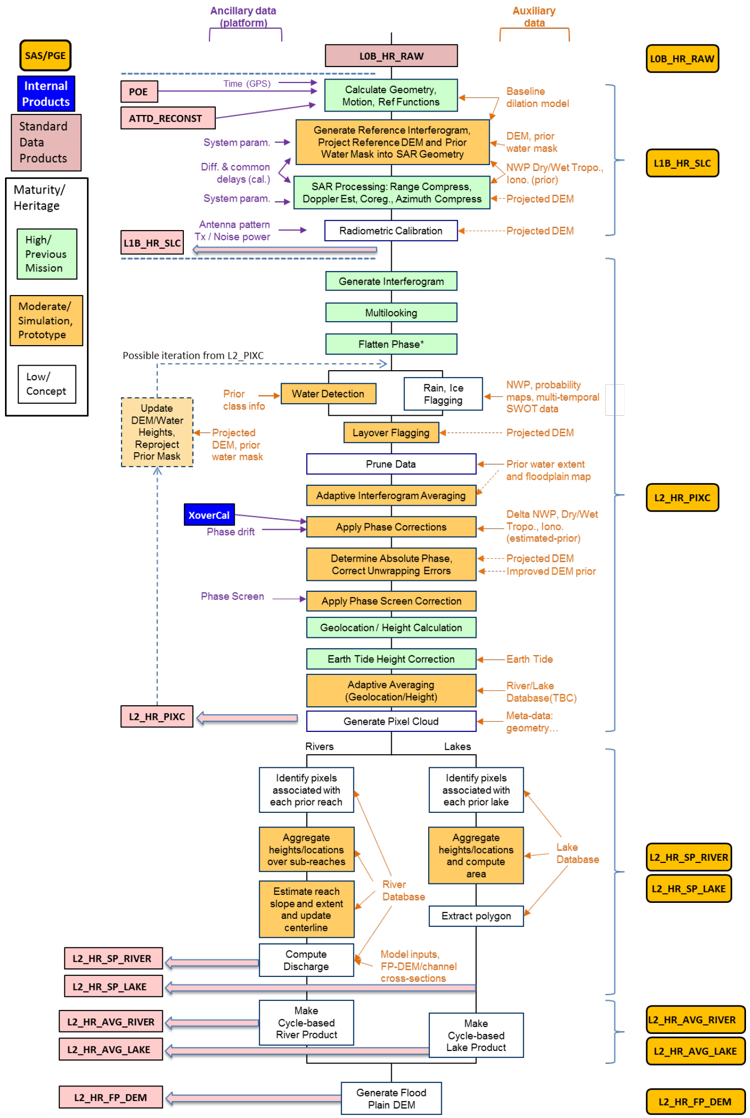


1 value per swath
Radiometer BT measurement in their geometry (at TBD° in the swath)
Other radiometer parameters

1 value at nadir along track
Time tag
Orbit data
Nadir altimeter measurement (Jason like product in a separate file)
TBD: some of the geophysical corrections or parameter and an associated algorithm to propagate across the swath
KNC data
NNI data (within a short swath over TBD km)

More details on L2 LR products on Wednesday (Nathalie Steunou et al.)

KaRIn HR Ground Processing Flow Diagram



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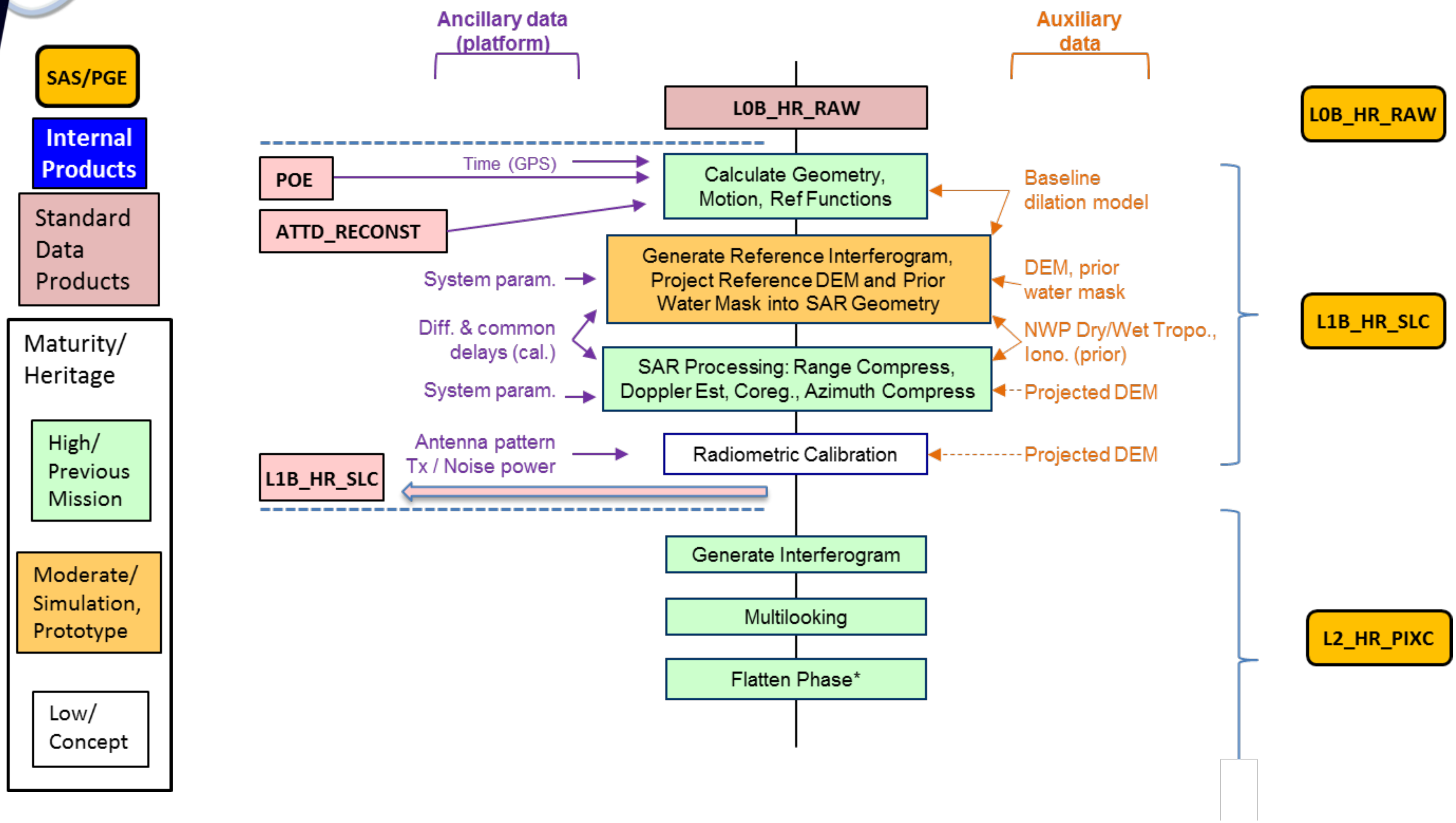

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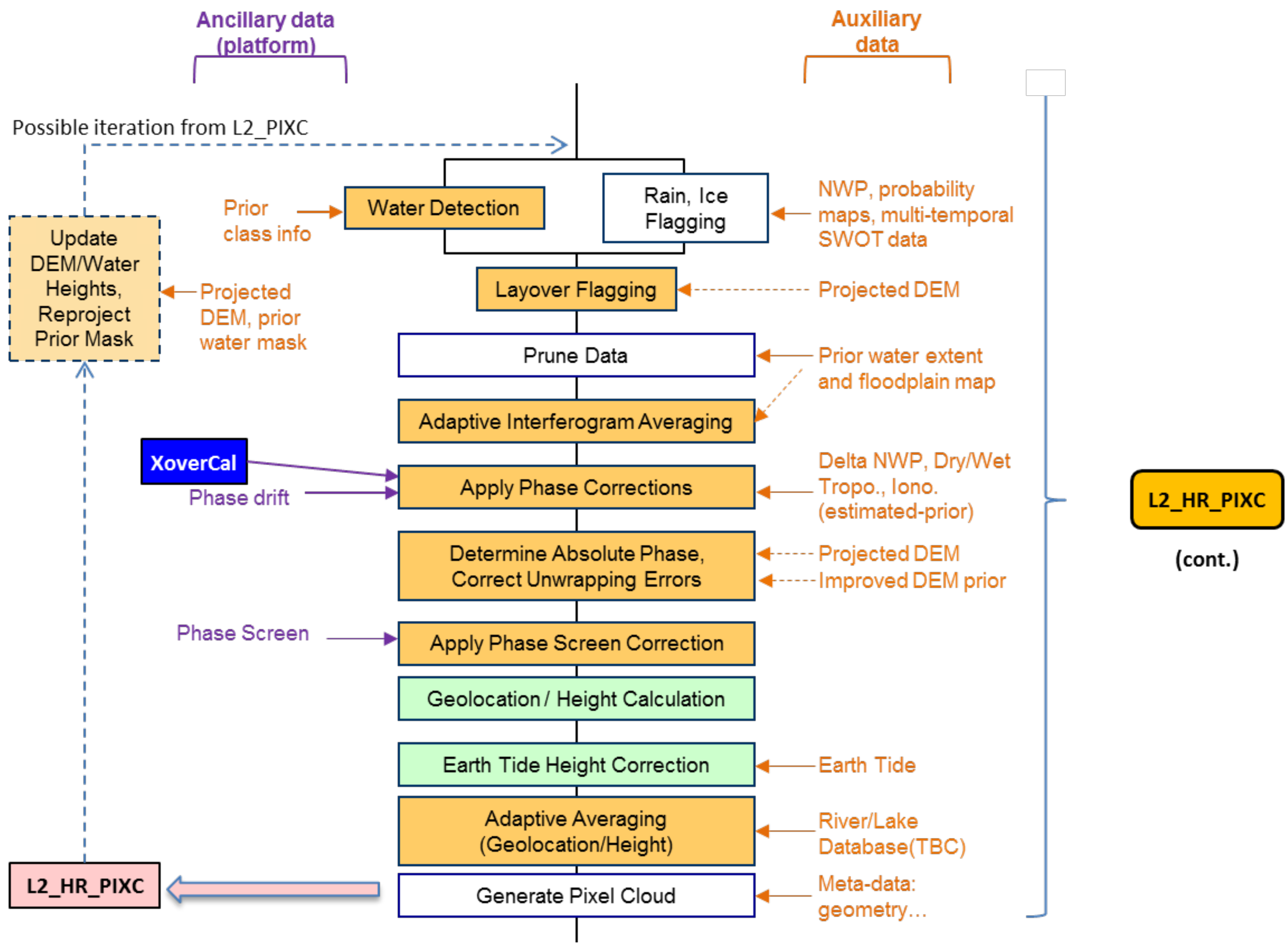
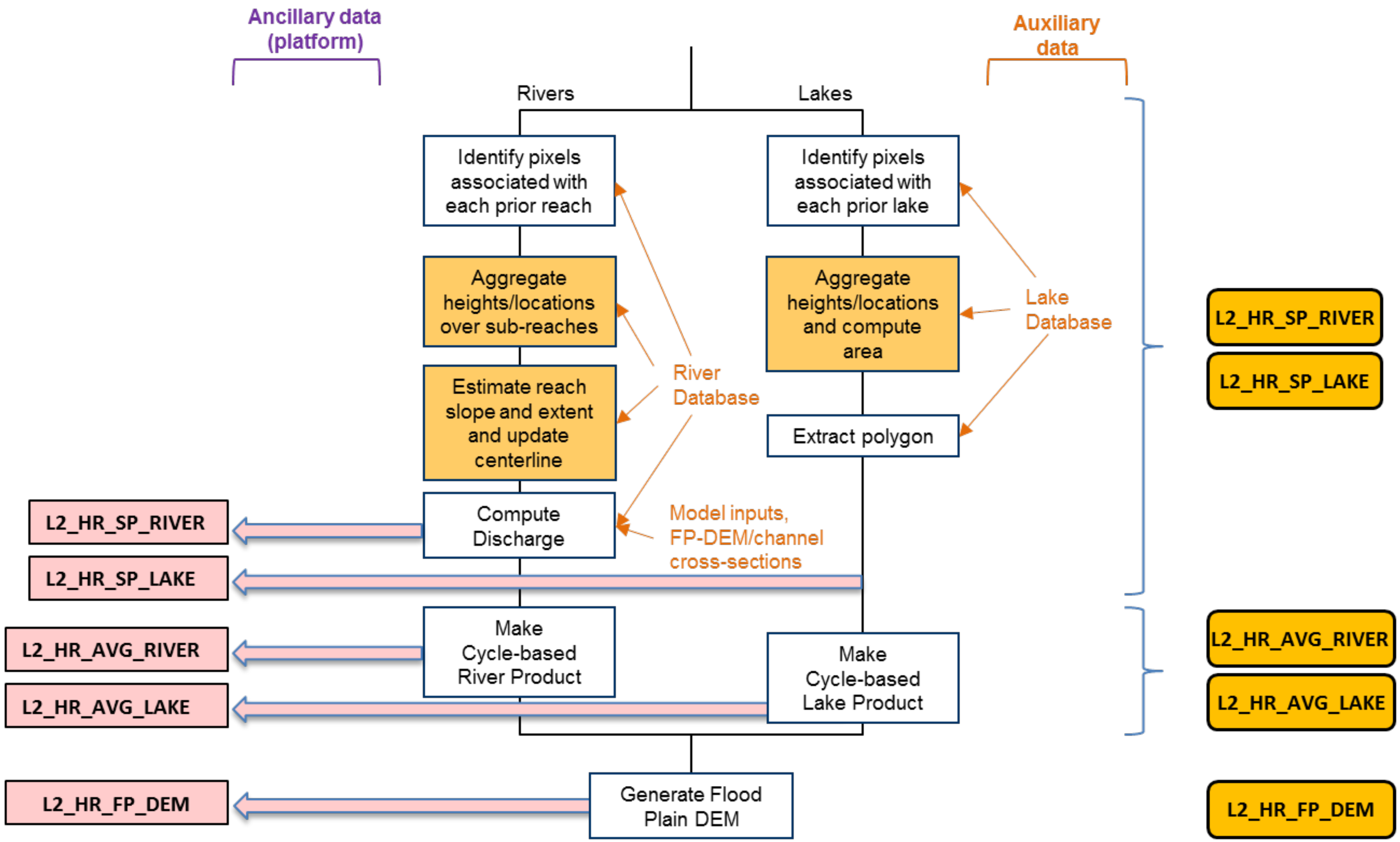


KaRIn HR Ground Processing Flow Diagram



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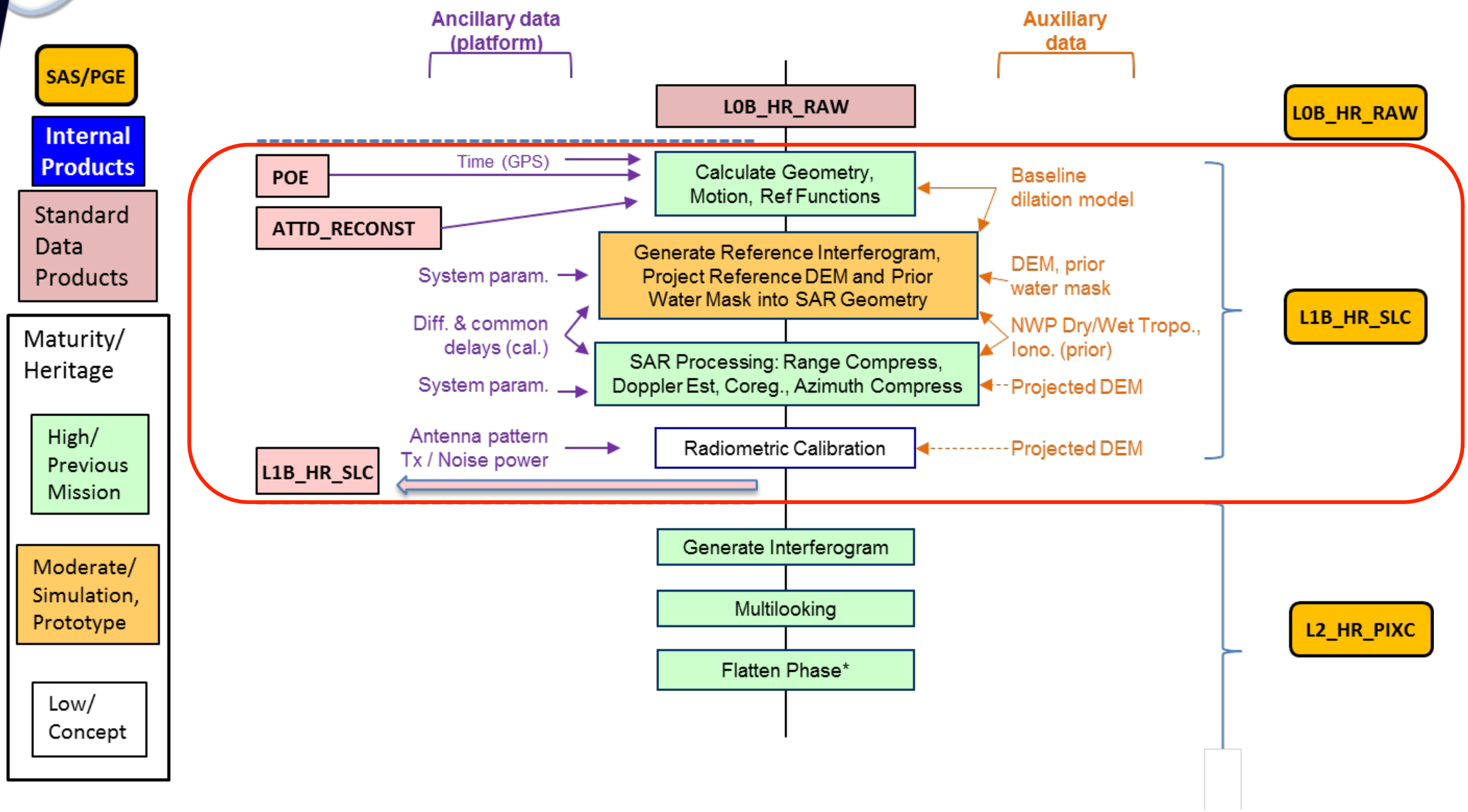
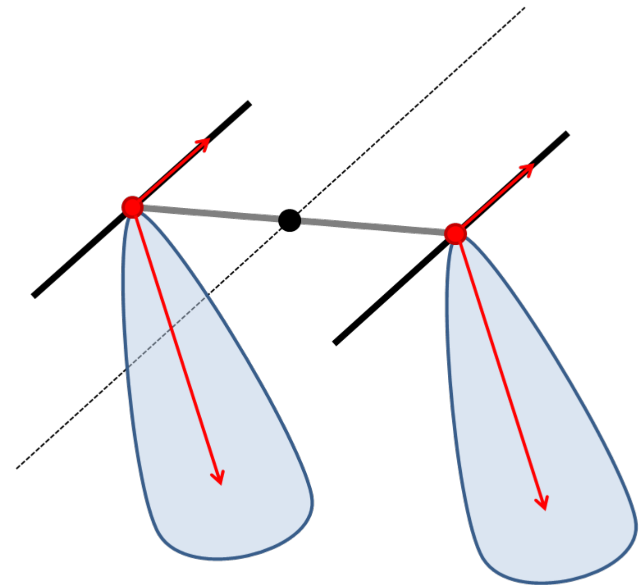


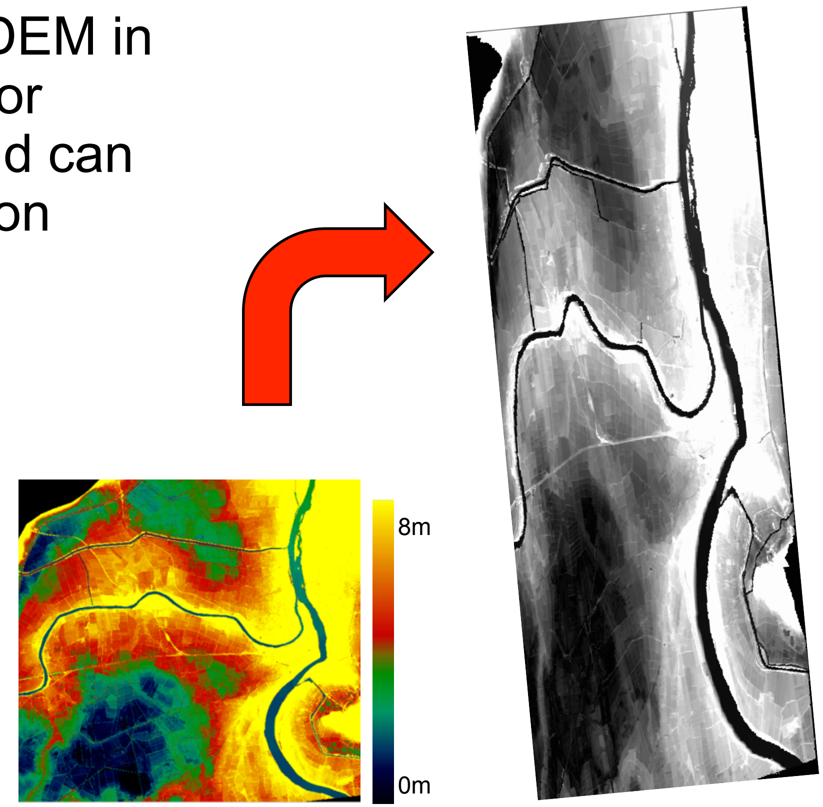
Calculate Geometry, Motion, Ref. Functions

- Same as for LR ground processing: compute the precise position and velocity of the phase center of each of the two antennas, as well as their orientation (antenna lobes), as a function of time (for each pulse).



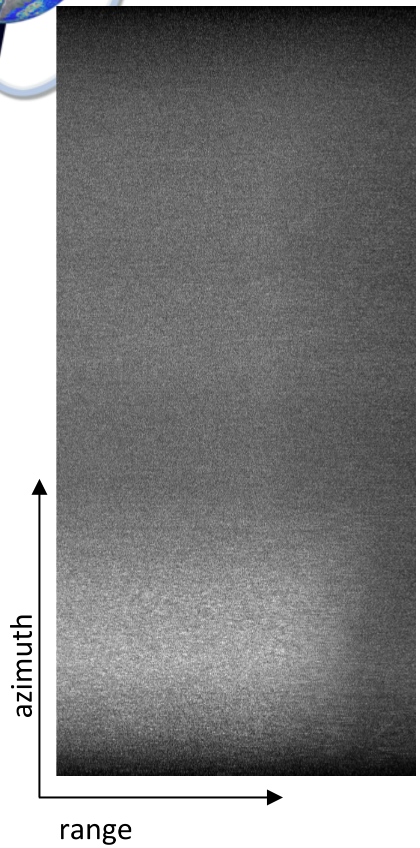
Project Reference DEM, Prior Water Mask in SAR Geometry

- Based on knowledge of acquisition geometry and timing, project the reference Digital Elevation Model (DEM) and the associated prior water mask (and possibly other spatial auxiliary data) in SAR geometry.
  - The projection of the reference DEM in SAR geometry defines the grid for time-domain SAR processing and can also be used for layover prediction
  - Projected prior water (probability) map is used to improve robustness of water detection and absolute phase determination
  - Possible update of projections after geolocation (iteration)

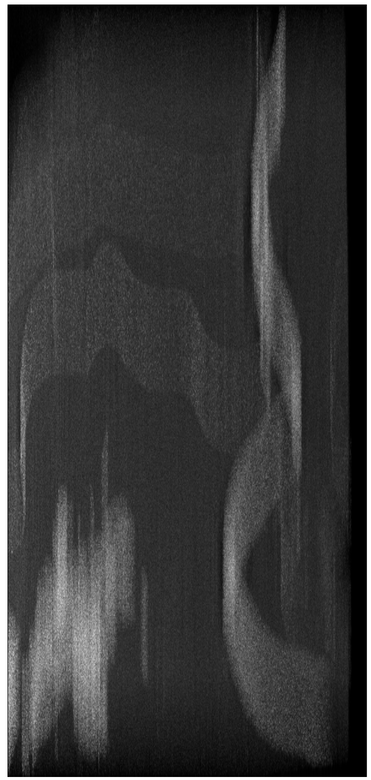


SAR Processing

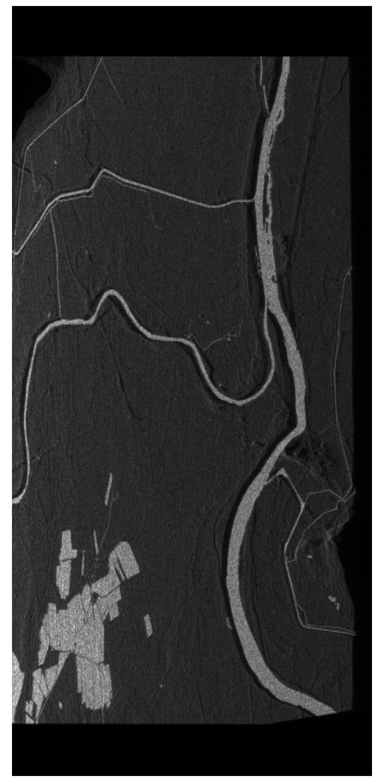
Raw data (from telemetry)



Range compression (improve range resolution)



Azimuth compression (improve azimuth resolution)



- Time-domain SAR processing
  - Integrates Doppler estimation, co-registration of the two channels, and phase flattening w.r.t. the projected reference DEM (possibly taking also prior ionosphere, wet and dry troposphere delays into account)

Radiometric Calibration

- Compute the so-called X-factor that maps σ_0 to noise-free signal power.

$$P_s = X\sigma_0 \qquad X = \frac{\lambda^2 P_t G^2 A}{(4\pi)^3 R^4 L_{sys}}$$

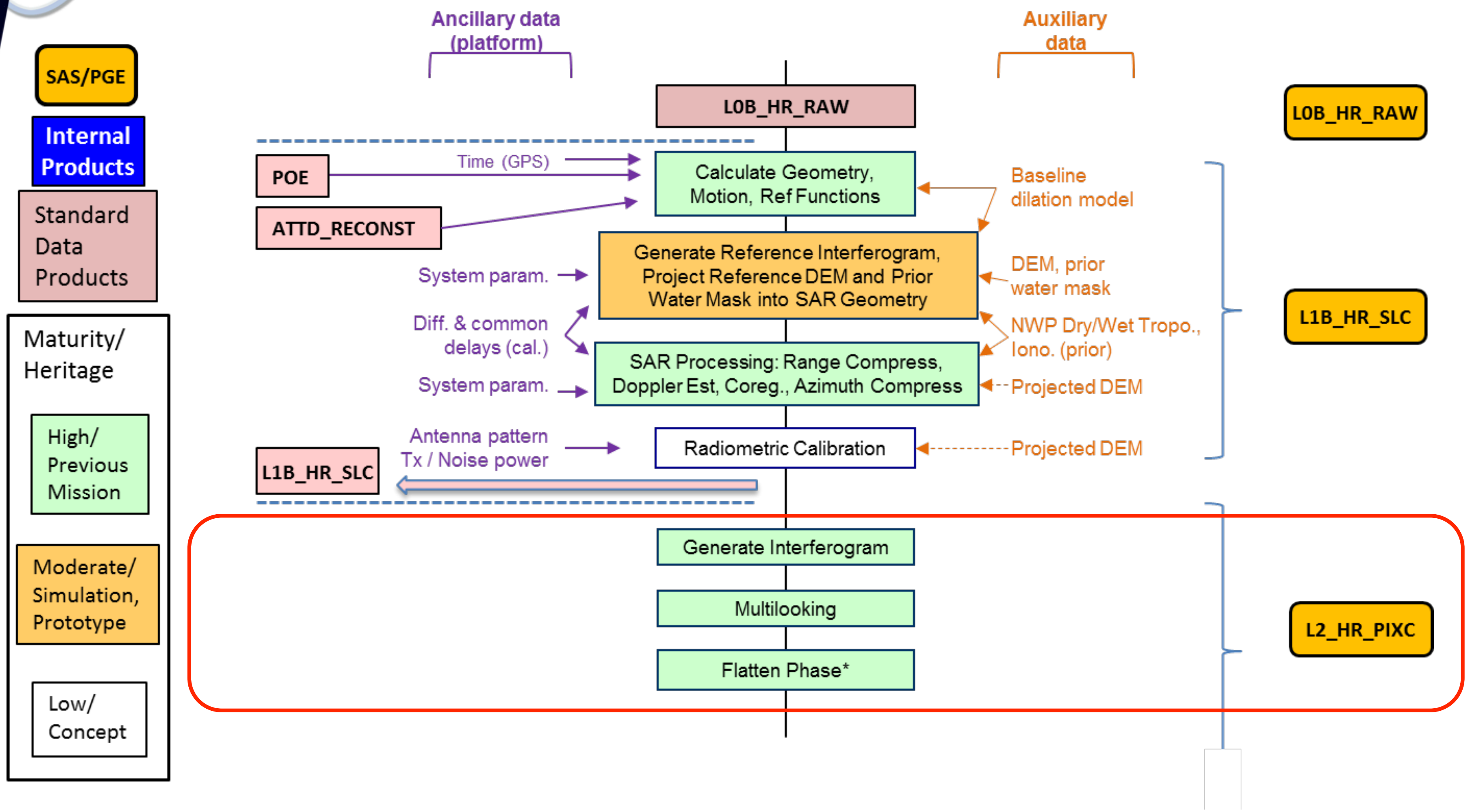
- The transmit power P_s is obtained from the calibration power measurements that monitor the drift over time, the range and area (*R*, and *A*) are computed from geometry, the gain term G is obtained from prelaunch antenna gain measurements, and the system losses L_{sys} are also obtained from calibration measurements.

- Also compute the Noise-equivalent-σ_0 (NESZ) which is the σ_0 that corresponds to a noisy measurement with no signal return.

$$\sigma_{neq} = \frac{P_N}{X}$$

- The noise power P_N is obtained from calibration measurements of system noise power (outside signal reception windows).

KaRIn HR Ground Processing Flow Diagram



Generate Interferogram, Multilooking

- The raw interferogram is simply the pixel-by-pixel product of the reference SLC f_1 and the complex conjugate of the coregistered secondary SLC f_2:

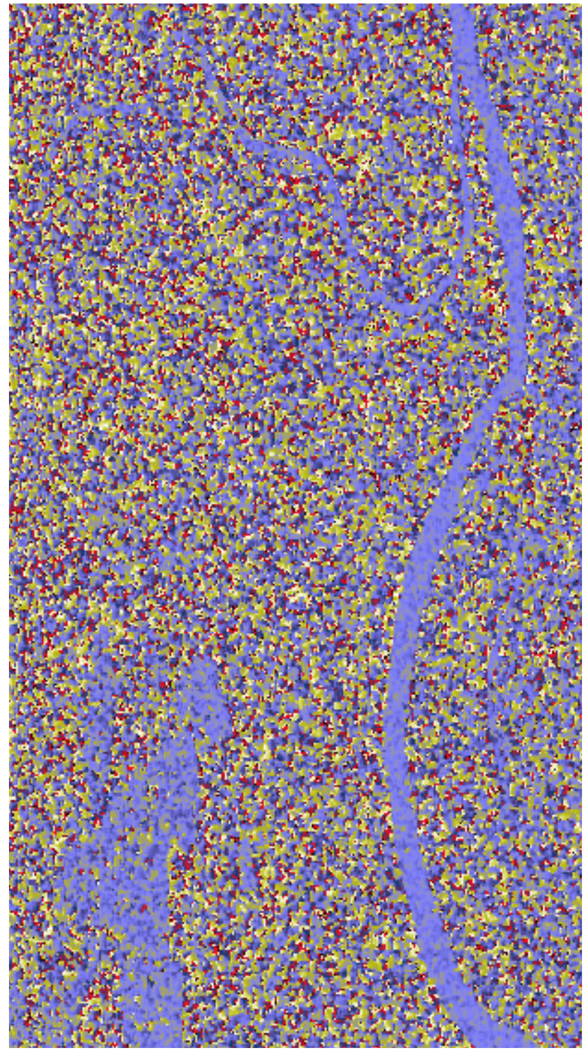
$$f_{\text{int}}(x,y) = f_1(x,y) f_2^*(x,y)$$

- Interferometric phase: $$\varphi(x,y) = \arg\left(f_{\text{int}}(x,y)\right)$$

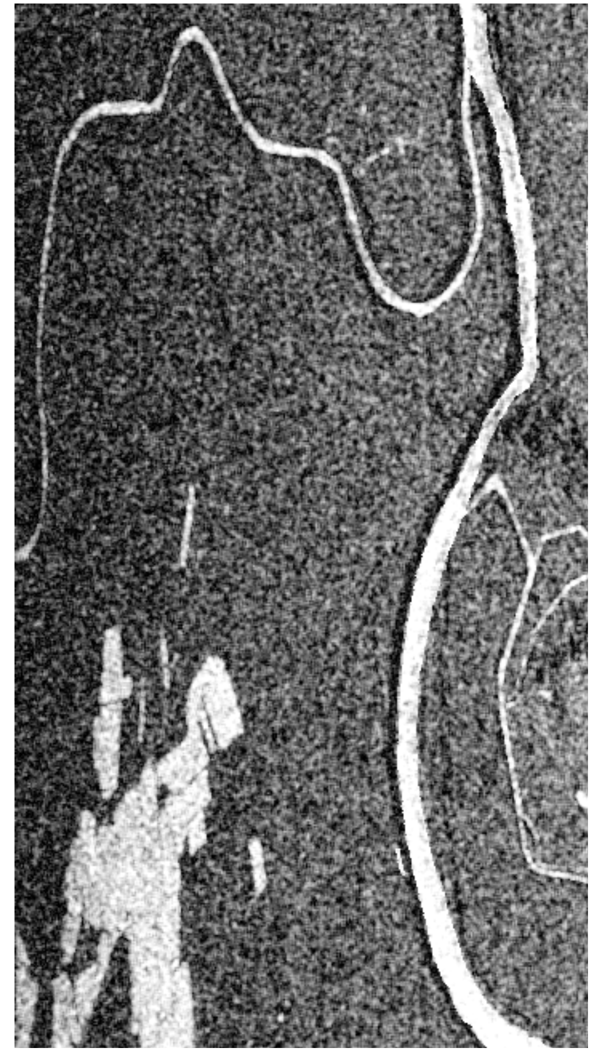
- Multilooking: block averaging of L pixels in the azimuth direction, reducing azimuth posting by L (currently L~4)
  - Interferogram: coherent average of the L complex interferogram pixels
$$f_{\text{int}}^{L}(x,y') = \sum_{y=Ly'}^{Ly'+L-1} f_1(x,y) f_2^*(x,y)$$
  - Power channels: incoherent average of L pixel powers for channel i=1, 2
$$P_i^{L}(x,y') = \sum_{y=Ly'}^{Ly'+L-1} f_i(x,y) f_i^*(x,y)$$
  - Coherence (correlation): $$\gamma(x,y') = \left|f_{\text{int}}^{L}(x,y')\right| \Big/ \sqrt{P_1^{L}(x,y') P_2^{L}(x,y')}$$

Example of Simulated KaRIn HR Interferogram

Amplitude (power)

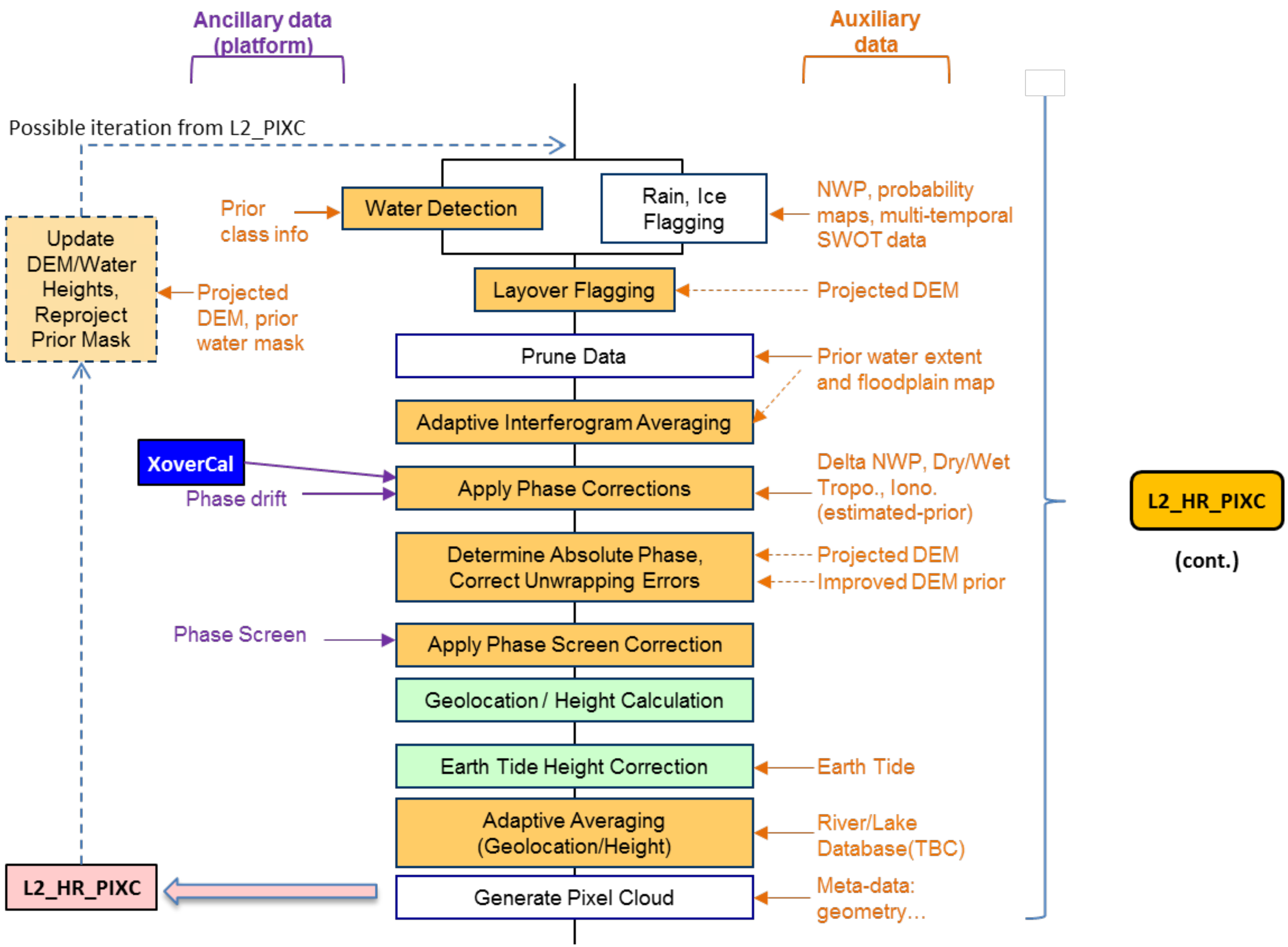


Phase (flattened) [0,2π]



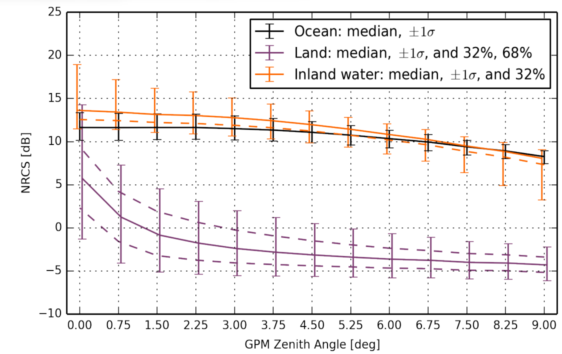
Coherence [0,1]

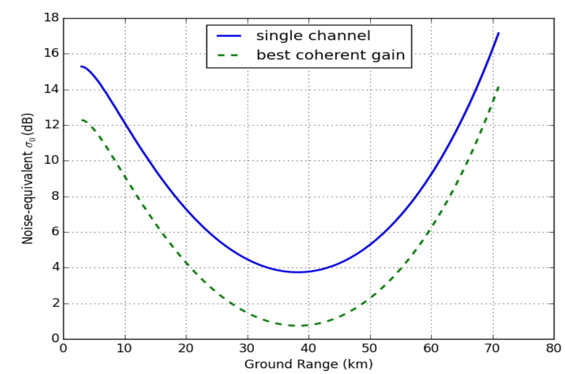
KaRIn HR Ground Processing Flow Diagram

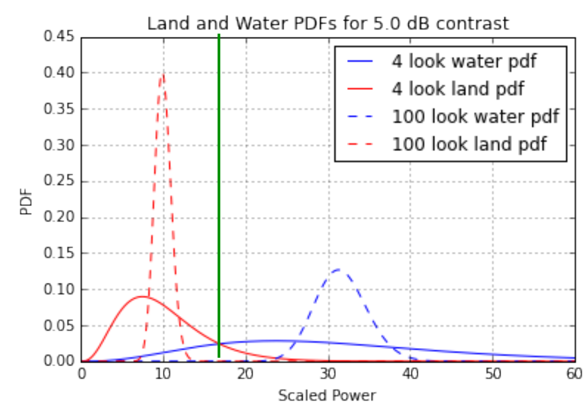


Water Detection

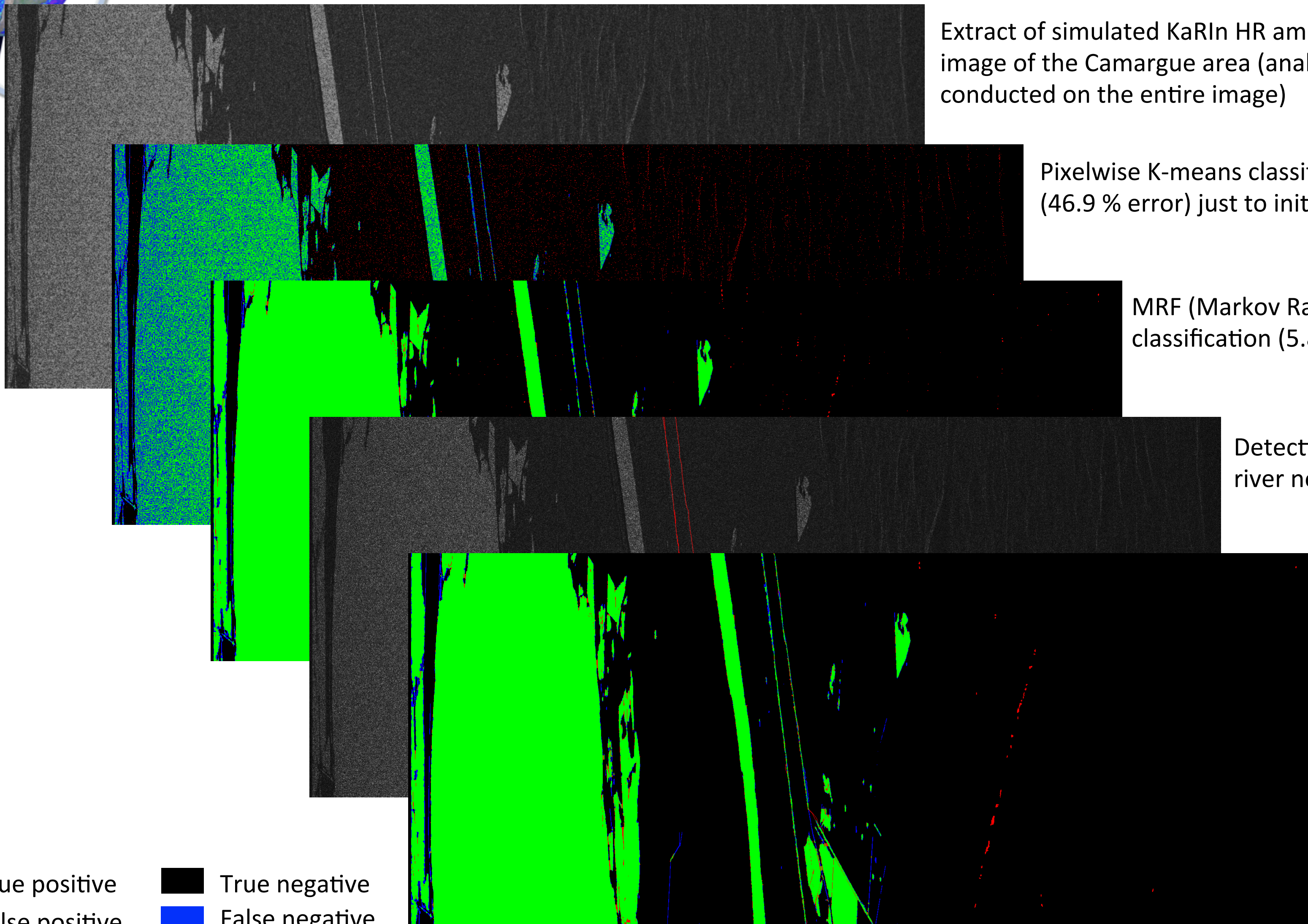
- Water signal is distinct from land signal
  - Primarily by the power/σ_0 (and the coherence)
  - Water is expected to be bright (σ_0 ~10-15 dB)
  - Most land types are dark (σ_0 ~ -5 to 0 dB)
  - But there are exceptions:
    - Dark water at very low wind speed
    - Some bright land types, e.g., roads, urban areas, hills/ mountains (layover)
- SWOT has high thermal noise floor
  - ~ 4dB noise-equivalent-σ_0 in best part of swath for single channel, but up to 3dB SNR gain by combining two channels powers coherently
  - Most land signals below thermal noise floor
- Several water detection algorithms developed
  - Pixel-wise Bayes detection, water fraction estimation
  - Contextual classification methods (MRF, snakes…)
  - Narrow river detection
  - Fusion schemes to combine the results
- Use of prior data for learning or in data fusion
  - Water mask, water probability map, DEM…
- Use of multitemporal data







Classification Results on Simulated KaRIn HR Image



Extract of simulated KaRIn HR amplitude image of the Camargue area (analysis conducted on the entire image)

Pixelwise K-means classification (46.9 % error) just to initialize…

MRF (Markov Random Field) classification (5.8 % error)

Detection of narrow river networks (in red)

Fusion of MRF and narrow river networks (5.6 % error)

True positive | True negative
False positive | False negative

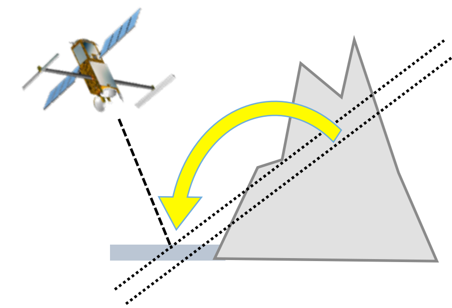
Rain, Ice Flagging

- Rain flagging:
  - The principle impact of rain on KaRIn/SWOT measurements is heavy attenuation (signal drop-out).
  - It is difficult to distinguish the rain signal from other dark classes (e.g., specular/dark water, forest, noise floor).
  - Use of auxiliary data: weather forescast, weather radars (NexRAD), scatterometers (ASCAT), altimeters (Altika), Precipitation Radar (GPM) etc.
- Ice/snow flagging:
  - The signal returning from ice/snow differs from land and water in two major ways: 1) producing a moderate power (~0dB sigma0, relative to ~-5dB land and ~10dB water), and 2) decreased coherence due to increased volume scattering.
  - It may be difficult to distinguish snow/ice from bright land or dark water, from the KaRIn/SWOT measurement alone.
  - Use of auxiliary data: regional/seasonal meteorological prior, data from other satellites (e.g. scatterometers, radiometers…)
  - Multitemporal analysis

Layover Flagging

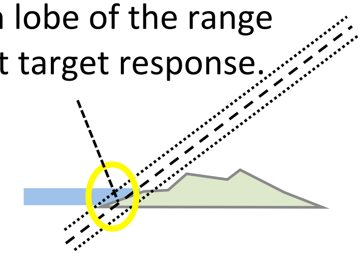
- Layover occurs when, due to topography or vegetation, returns from separate areas on the ground come back at the same time
- When returns from the terrain "lay over" water pixels, the measured water heights will have a bias (and a geolocation error) that is basically proportional to the relative difference in heights, contrast, and illuminated areas.
- Additionally, the boundaries of the water bodies will have "mixed pixels", which also combine land and water contributions.

Layover: points within the lines produce a return in the same range bin



- Two approaches for layover flagging:
  - Geometric prediction based on a reference DEM
    - Detection of geometric inversion (slant/ground range)
    - Highly dependent on DEM resolution and accuracy
  - Detection of data anomalies due to layover
    - Coherence (but two opposite effects – may cancel)
    - Phase or height slopes (averaging over large area)
    - Use of multitemporal data to improve resolution

Mixed pixel: land and water inside the same main lobe of the range point target response.

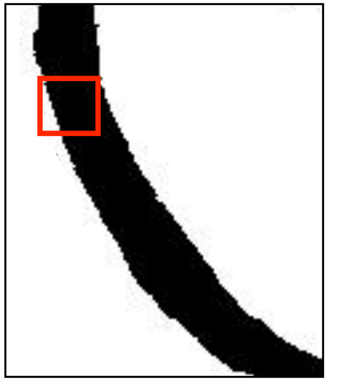


Prune Data

- In order to reduce data volume, only pixels that are expected to be useful in meeting downstream science objectives are preserved.
- These include pixels detected as water, as well as pixels in a buffer zone around all expected surface water given some prior maximum water extent mask.
- The inclusion of this buffer zone enables generation of the floodplain DEM from the pixel cloud and preserves the lowest level data that can be expected to be hydrologically useful.
- The pruning is expected to reduce the number of pixels for further processing and storage by a factor of ~10.

Adaptive Interferogram Averaging

- Further averaging of the complex interferogram (and channel powers) to reduce phase noise prior to phase-to-height conversion and avoid loss of height precision
- Interferogram averaging is more efficient than averaging of 3D coordinates up to ~50 looks
- Realized with a shape-adaptive sliding window (size ~3x3-5x5)
  - Only average pixels within same class (water or land/buffer)
  - Keep the same posting (~4 looks)

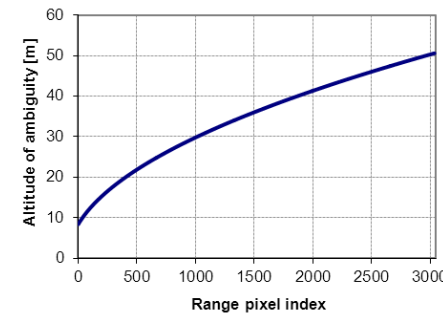


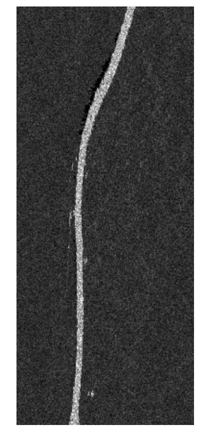
Apply Phase Corrections

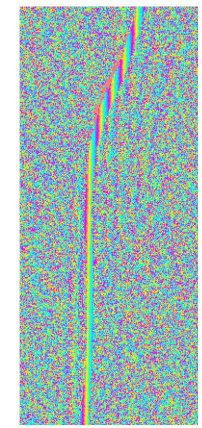
- Apply the phase corrections listed below to the flattened, multilooked and pruned interferogram.
- Similar to the corresponding LR corrections, except that they are applied to phase rather than height, and that radiometer and Ku/C measurements cannot be used to compute range delays over land.
  - Phase drift correction: compensate measured instrument drift between the reference and secondary channel (slow variation).
  - Wet/dry troposphere: based on NWP model (ECMWF, MERRA…)
  - Ionosphere: GIM (GPS Ionosphere Model)
  - Crossover calibration: ocean crossover roll estimates, interpolated over land
- Prior models for some range delay corrections may be applied during SAR processing, in which case the corrections applied here are the differences between the estimated and prior corrections.

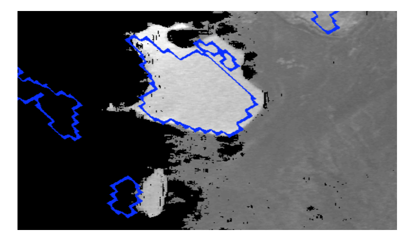
Phase Unwrapping, Absolute Phase

- The phase is flattened w.r.t. the reference DEM but residual fringes will occur due to limited DEM resolution and accuracy (when error > ±4 m in near range and > ±25 m in far range)
- Algorithm concept:
  1. Classic spatial phase unwrapping
     - Use minimum cost flow based algorithms to unwrap phase of detected water bodies (heritage from AirSWOT, SRTM reprocessing, …)
     - The results will be disconnected regions with undetermined 2π ambiguity for each region
  2. Correct phase ambiguity inconsistency within each water region
     - Using continuity of each water region and water surface flatness to determine relative phase ambiguity
  3. Determine phase ambiguity for each water region
     - Use DEM and other prior information
     - Slope anomalies and range shifts indicate ambiguity error
- Reference DEM: SRTM v3, NASADEM, TanDEM-X…?
- Reference water heights can be improved with SWOT measurements









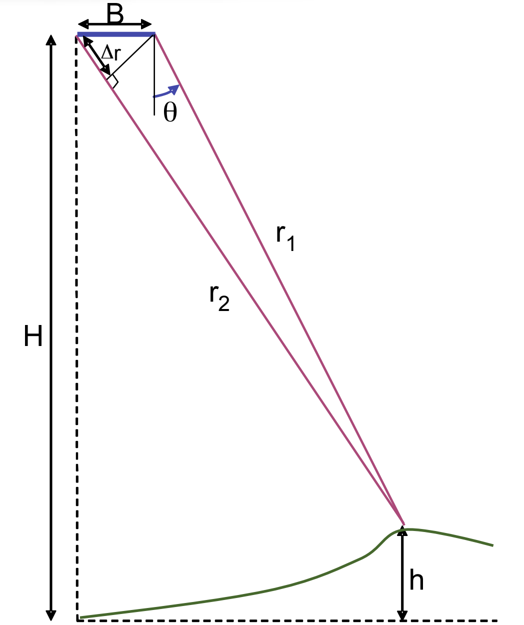
Apply Phase Screen Correction

- The phase screen is a phase error caused by multi-path reflection of the antennas and the close-by platform structures. It depends on the echo arriving direction of the target (look angle) and can be approximated as a function of the absolute interferometric phase.
- The phase screen correction must therefore be done after absolute phase determination.
- This phase term is very slow function of time and will be determined from cross-over paths by the post-calibration.
- After phase drift and phase screen correction, we get the absolute interferometric phase, which will be used for determining geolocation of each image pixel.

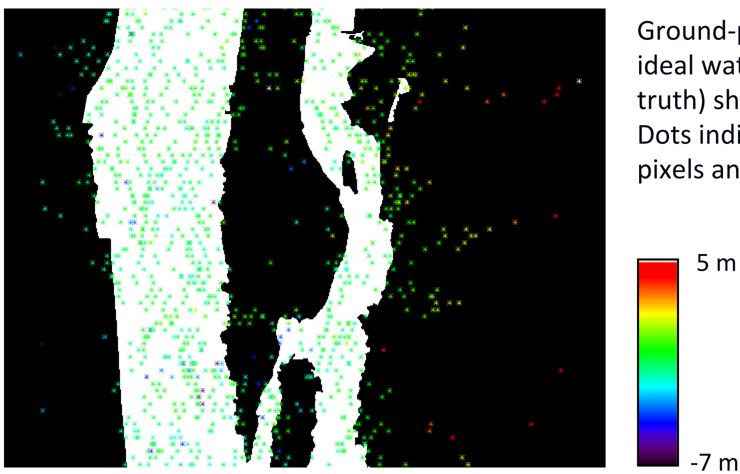
Geolocation / Height Calculation

- Basically the same principle as for computation of geolocated heights in LR mode.

- Invert absolute interferometric phase into geolocated heights, using the direct geocoding equations



Example



~50-look geolocation *[medium]*

Ground-projected (lat,lon) ideal water mask (ground truth) shown in white. Dots indicate geolocation of pixels and color = height.

Earth Tide Height Correction

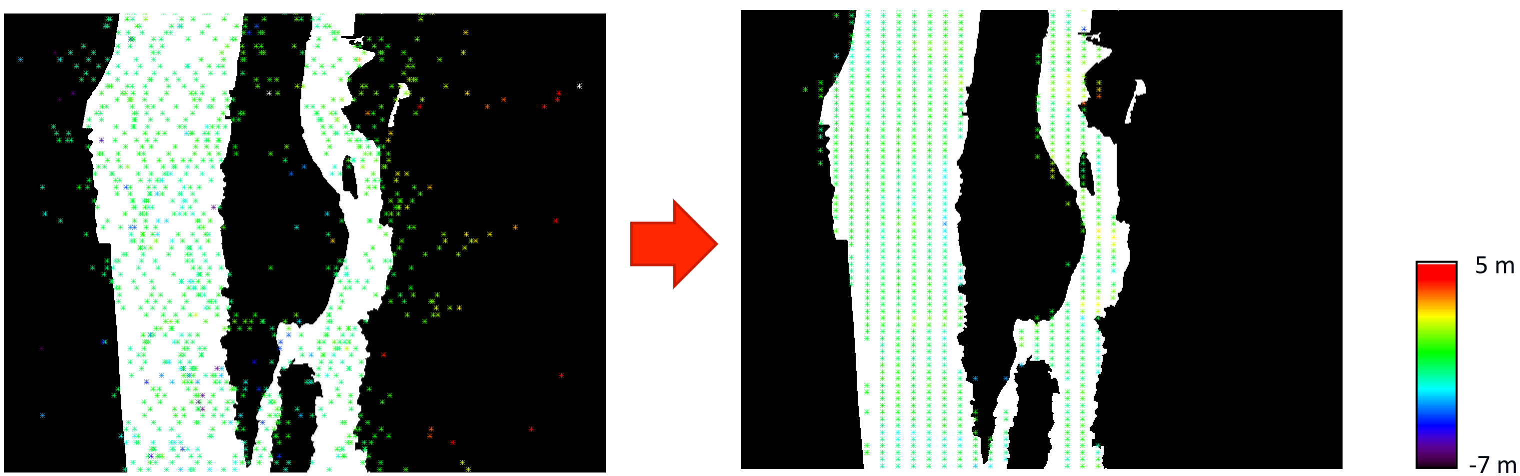
- Correct the earth tide after the geolocation of each pixel of the pixel cloud product has been determined.
- The earth tide is the displacement of the solid Earth's surface caused by the gravity of the Moon and the Sun.
- The displacement is function of time and geolocation.
- Earth tide displacement model used for earlier missions (legacy system).

Adaptive Averaging (Improved Geolocation)

- Further averaging to generate, in addition to the principal (lat,lon,height) triple, an additional (lat,lon) pair with improved geolocation, in order to facilitate the use of L2 HR data.

- Several approaches proposed:
  - Further shape-adaptive averaging (big window)
  - MAP estimate using prior heights (that can be iteratively improved)
  - Regularization of entire detected water bodies, reaches or lakes based on spatial relationships and estimated height/slope

Example



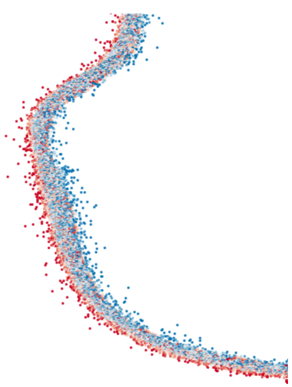
~50-look geolocation *[medium]*   Improved geolocation *[well-done]*

Generate Pixel Cloud

- Gather results of L2 HR processing steps to produce the pixel cloud
- The pixel cloud is a compact representation of the results of water detection, layover, rain and ice flagging, data pruning, instrument and geophysical corrections, and estimation of geolocated heights

[rare]
~4 looks

Posting kept close to full resolution (~4 looks) to be able to accurately represent rivers > 50 m, lakes > 100 × 100 m^2, and to perform only minimal averaging of information
- water mask with layover/rain/ice flags, estimated water fraction
- slant range pixel coordinates, ground-projected pixel size
- phase-flattened interferogram, phase corrections (TBC)



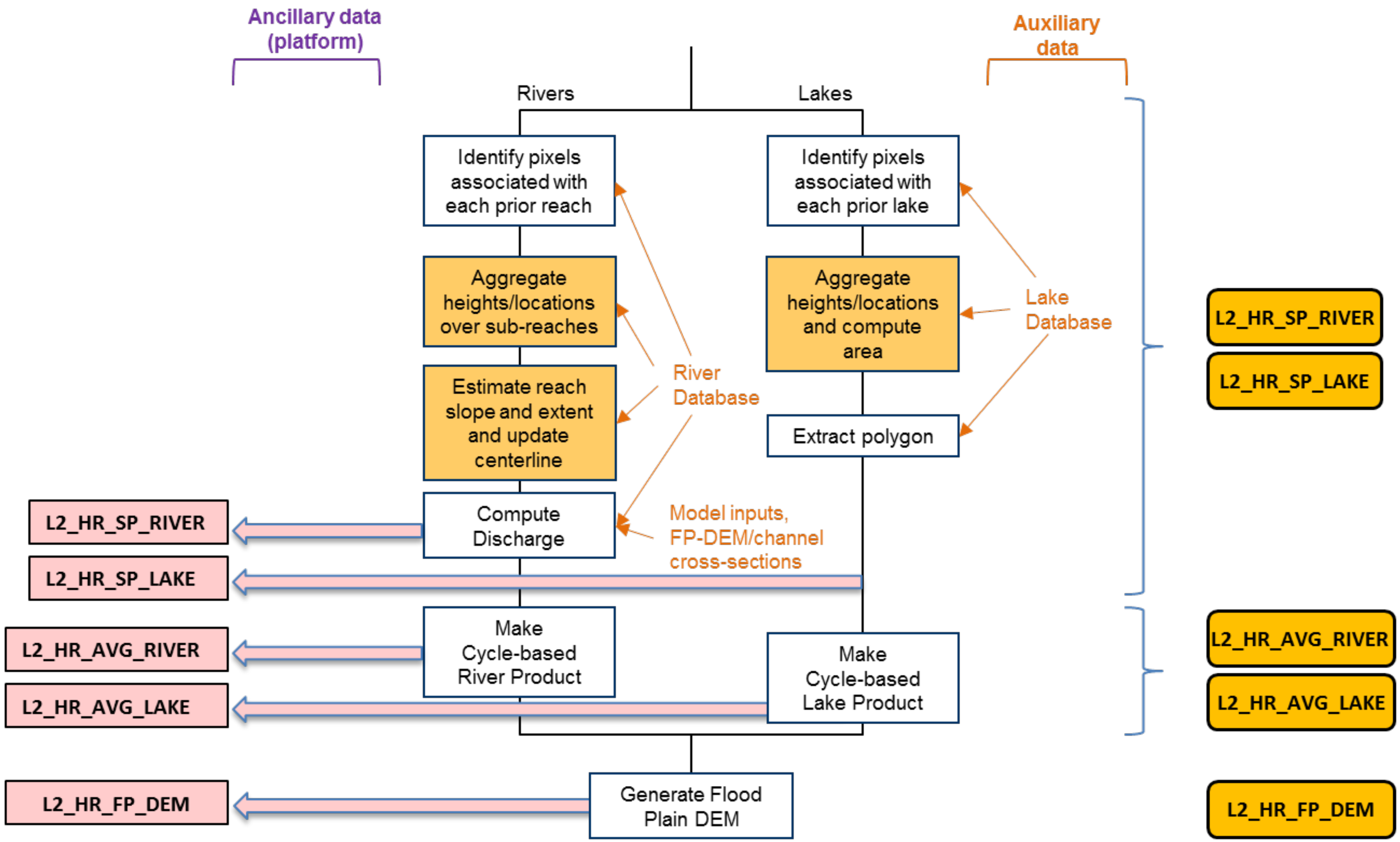
[medium]
~50 looks

Additional interferogram averaging up to ~50 looks prior to phase-to-height conversion to optimize precision while preserving water surface topography
- (lat, lon, height) and associated uncertainties

[well-done]
>>100 looks

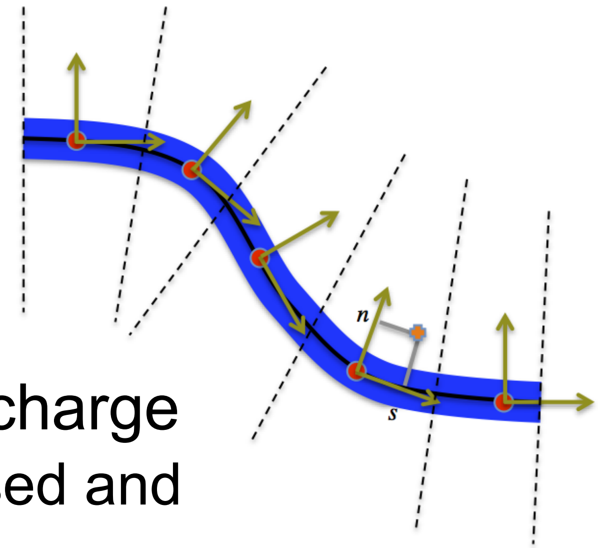
Further adaptive averaging >> 100 looks to improve geolocation
- improved (lat, lon)

KaRIn HR Ground Processing Flow Diagram



Compute River Vector Products

- Prior database of river reaches, centerlines
- Identify water pixels associated with each prior reach
- Aggregate heights/locations along the centerline
- Estimate reach slope and extent and update the centerline



- Concept implemented (RiverObs)

- Computation of reach-averaged discharge
  - Several algorithms have been proposed and compared ("Pepsi challenge")
  - Substantial Science Team effort on algorithms and prior data

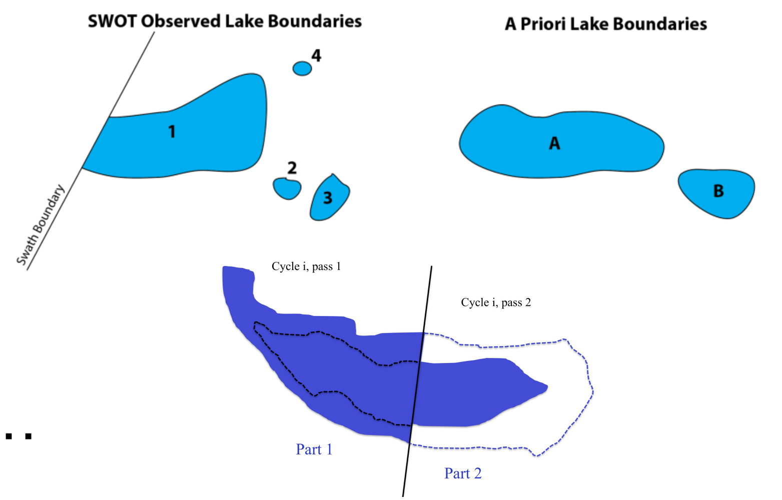
- Cycle-based (or monthly) average product
  - Based on stack of pixel clouds

Compute Lake Vector Products

- Prior database of lakes
- Identify water pixels associated with each prior lake
- Aggregate heights/locations and compute area
- Extract polygon ⇨ Pass-based lake product

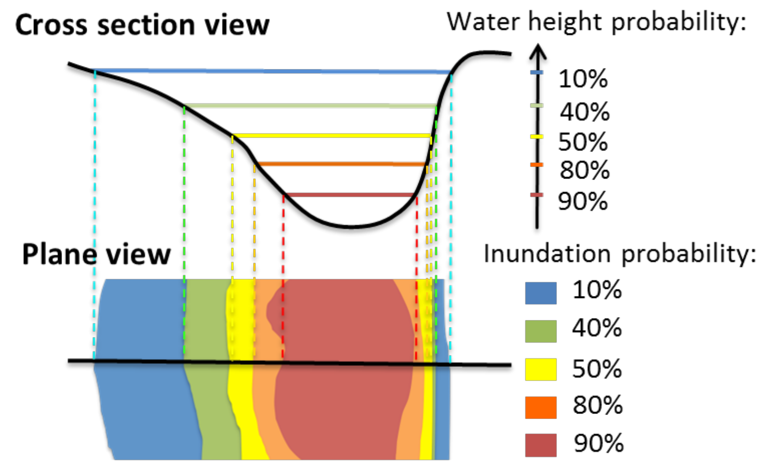
- Cycle-based (or monthly) lake product
  - Merged lake regions based on stacked information
  - Includes computation of storage change

- Challenges
  - Mismatches between detected and prior water masks
  - Partial observation (swath coverage, dark water)
  - Lakes appearing, disappearing…



Floodplain DEM

- Two concepts
  - **Bathtub ring**: use water heights for edge pixels used to estimate floodplain DEM elevations (limited to observed min/max water heights)
  - **Interferogram stacking**: use land phase, but need to beat down noise before geolocation (multitemporal averaging)
  - Final product combining both (complimentary approaches)
  - Option: update bathtub method continually with inline algorithm, then generate with stacking approach and combine offline on ~yearly interval



Floodplain DEM and water probability maps are related:

- Thresholding the probability maps gives a unique water mask for a given water height /stage

Algorithm Status and Outlook

- The SWOT Algorithm Development Team (ADT) has elaborated preliminary LR and HR algorithm flows.
- The preliminary algorithm flows and individual steps are described in the Algorithm Description Document (ADD).
  - Represents current understanding, often with several options
  - Both flows and individual algorithms are likely to evolve.
- Prototyping and testing of algorithms on simulated SWOT data of increasing realism, and on AirSWOT data.
- Selected algorithms will be further detailed in Algorithm Theoretical Basis Documents (ATBDs).

- Science Team (ST) members can and are encouraged to contribute to algorithm development, prior data.
  - More on algorithm development, prior data and the interface between ADT and ST on Wednesday.

Backup

Processing of SWOT Data

- Considerable heritage from nadir altimetry processing for
  - Nadir altimeter
  - Radiometer (though in each KaRIn swath rather than nadir)
  - DORIS/GPSP (Precise Orbit Determination)
  - Attitude (also from other satellite missions, AirSWOT…)

- Remainder of presentation devoted to KaRIn processing
  - Low Rate (LR) data mainly for oceanography, acquired continuously over both ocean and land
  - High Rate (HR) data mainly for continental hydrology, acquired over HR mask only
  - Some heritage from nadir altimetry processing, but principally from spaceborne and airborne SAR interferometry (SRTM, AirSWOT...)

Receive Only Noise Estimation

- To estimate the noise power level $\overline{n}$ of the acquisition system, data are regularly recorded at times where no pulse is being received (no signal, only noise), for each channel and swath.
- The receiver noise estimate has to be averaged to reduce the error. The averaging interval will be selected based on the on-orbit variability. Outliers will not be used for the averaging, and will be flagged for further investigation.
- This receive-only noise is required to compute the normalized radar cross section (NRCS, also referred to as σ_0), the SNR...

Amplitude Correction

- Radiometric calibration of each power image applying only propagation and instrument corrections (but no geophysical corrections).

$$\sigma_0 = A_{corr}\left(P_{rx} - \overline{n}\right)$$

$$A_{corr} = \frac{(4\pi)^3 R^4}{P_{tx} G_{tx} G_{rx} \lambda^2 A_{rc}}$$

  – Requires knowledge of platform attitude and instrument properties (transmitted power, antenna gains), range cell size, range, etc…
  – Computed as a correction factor, applied later

Geometric/Angular Correlation Estimation

- Needed to invert SWH from total correlation (coherence)

$$\gamma^{(J)} = \gamma_n^{(J)} \gamma_{\varphi,g}^{(J)} \gamma_{vol}^{(J)}$$

noise angular/geometric volume

- Geometric/angular decorrelation is due to the fact that
  - pixels are not points, but surfaces with an extent, and that the interferometric phase difference varies throughout the resolution cell,
  - the misalignment of iso-range and iso-phase (cfr. phase bias).
- The angular correlation equation is specific to the SWOT OBP algorithm.

SNR, σ_0 and Noise Correlation Estimation

- SNR and σ_0 computed based on the SAR power images, the receive-only noise power and the amplitude correction

$$SNR^{(J)} = \frac{P_{rx}^{(J)} - \bar{n}^{(J)}}{\bar{n}^{(J)}}$$

$$\sigma_{0,uncorr}^{(J)} = A_{corr}^{(J)} \cdot (P_{rx}^{(J)} - \bar{n}^{(J)})$$

- Noise correlation estimated directly from the SNR of the two channels

$$\gamma_N^{(J)} = \frac{1}{\sqrt{\left(1 + \frac{1}{SNR_1^{(J)}}\right)\left(1 + \frac{1}{SNR_2^{(J)}}\right)}}$$