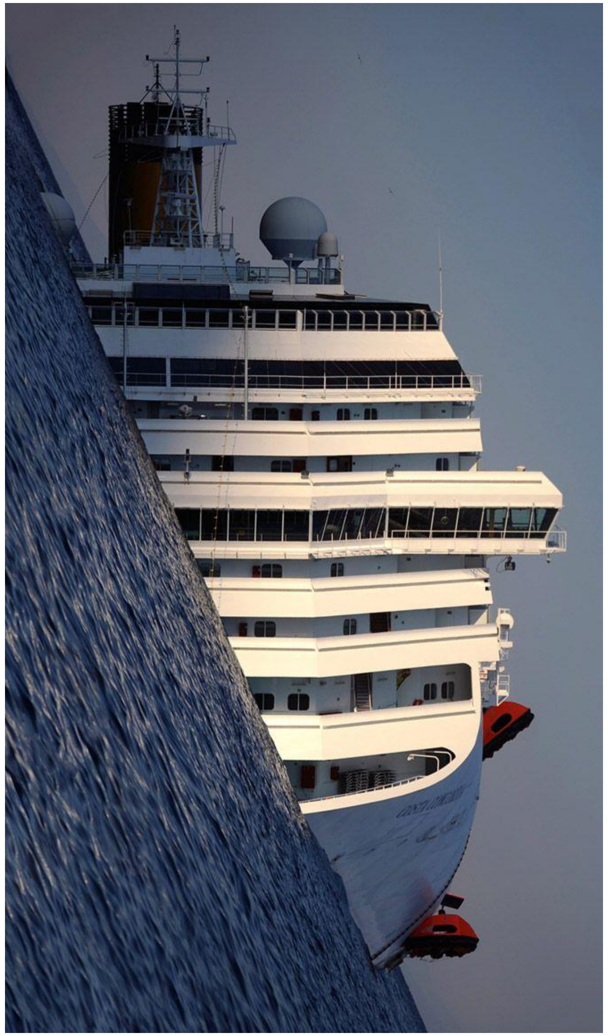
Data-driven calibration rationale & limits
How it may affect ocean users

G.Dibarboure (CNES), C.Ubelmann (DATLAS)

Why do we need data-driven calibration?

The short answer is…

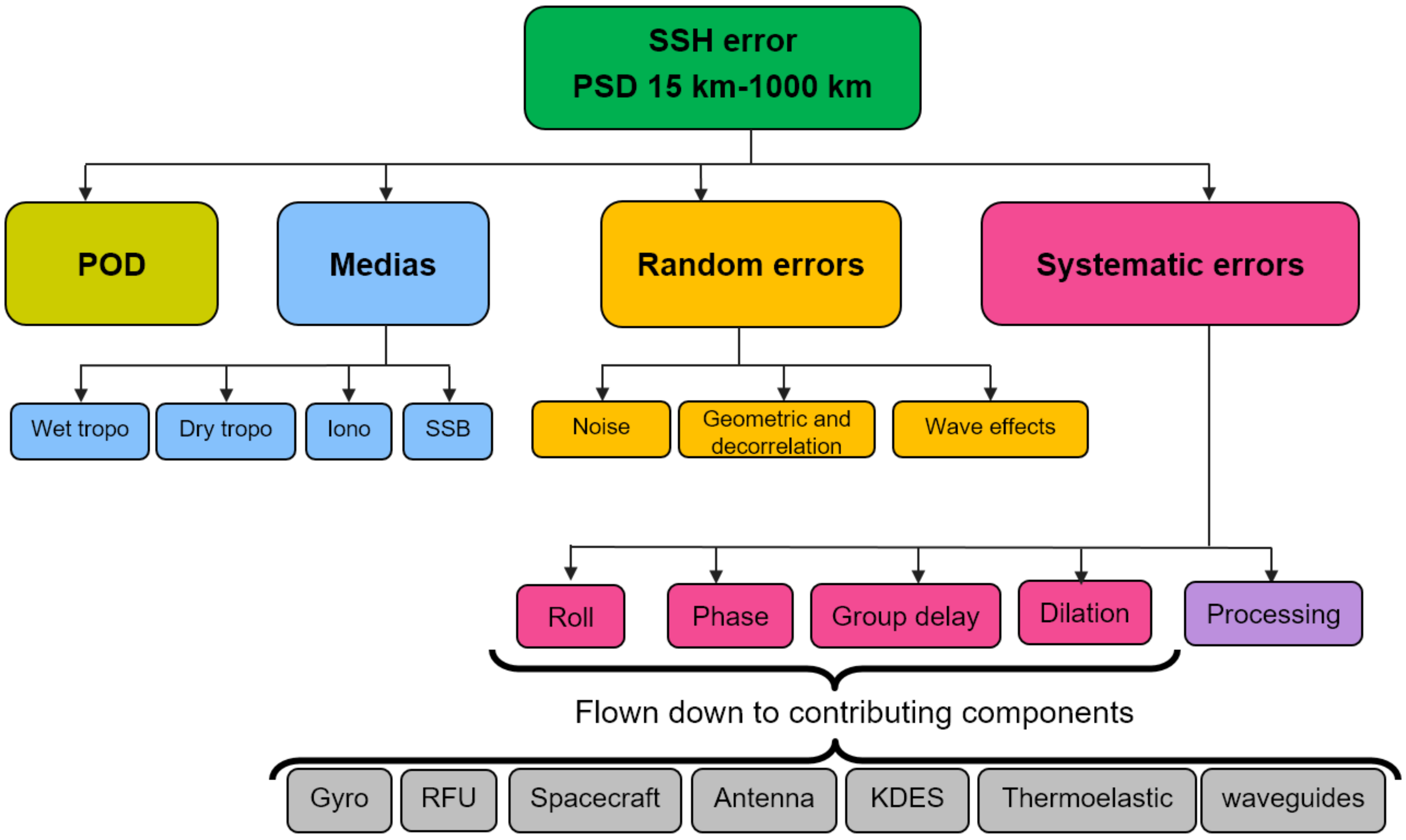
…because you don't want the KaRIn topography to look like this [1]



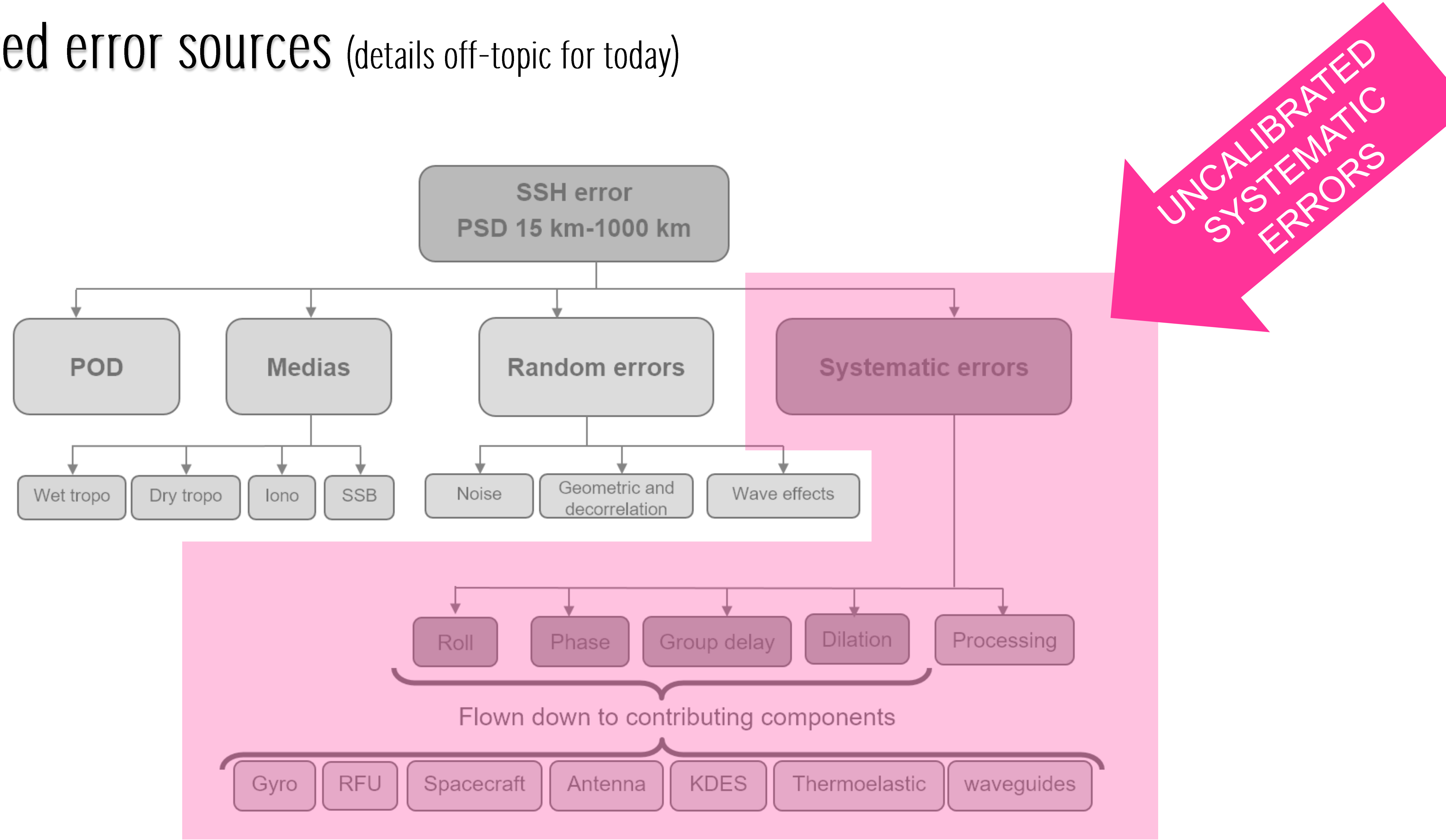
…and neither do hydrologists

[1] This is obviously grossly exaggerated. Actual numbers in Project talks.

KaRIn's error budget breakdown (off-topic for today)



Uncalibrated error sources (details off-topic for today)



Examples of KaRIn systematic errors

Antenna roll angle is not perfect?

Phase error in processing?

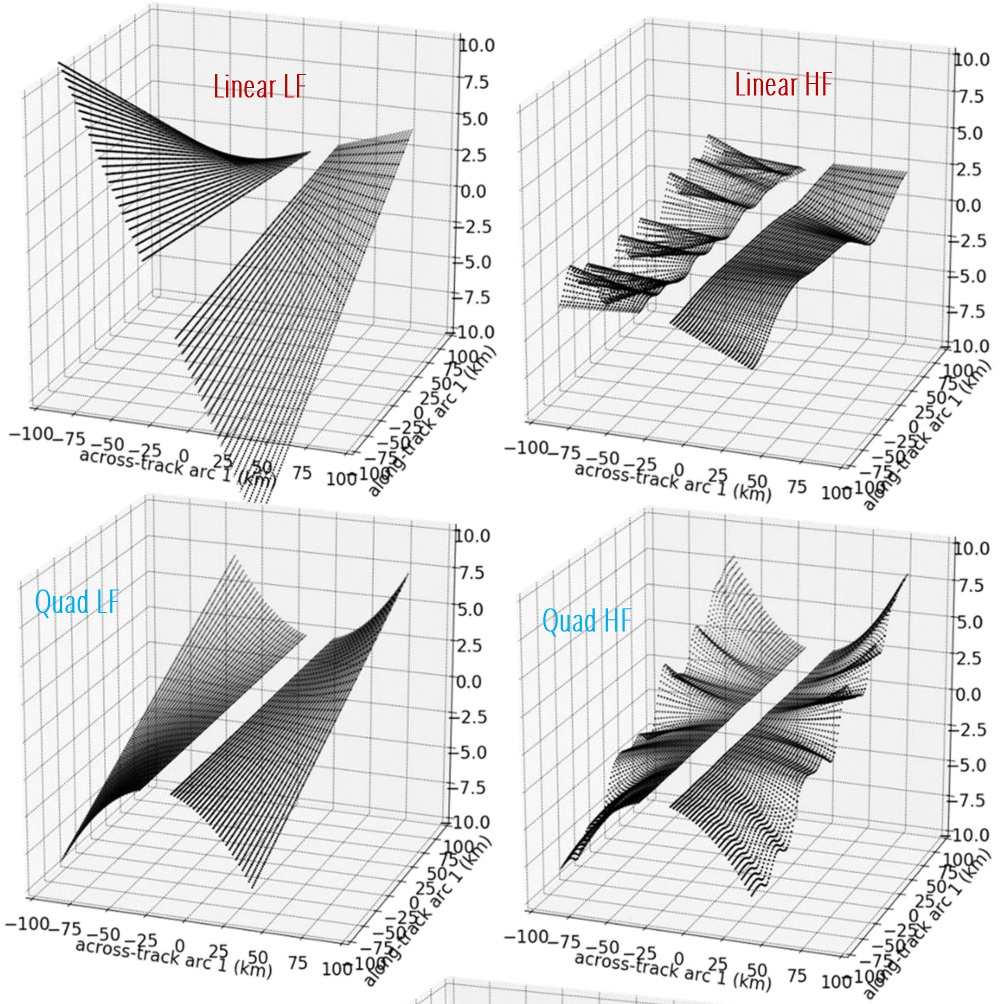
➡ Linear cross-track topography

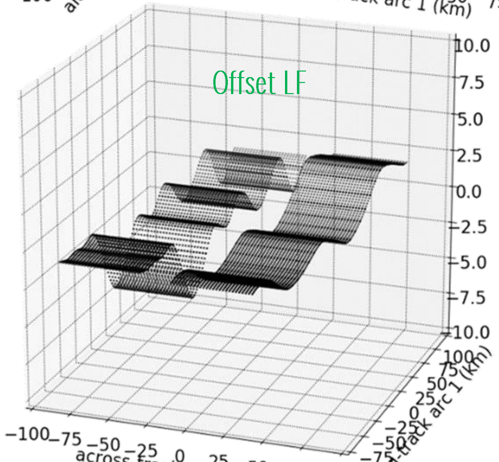
Baseline length is not perfect?

➡ Quadratic cross-track topography

Range timing bias in KaRIN?

➡ Time-varying offset topography

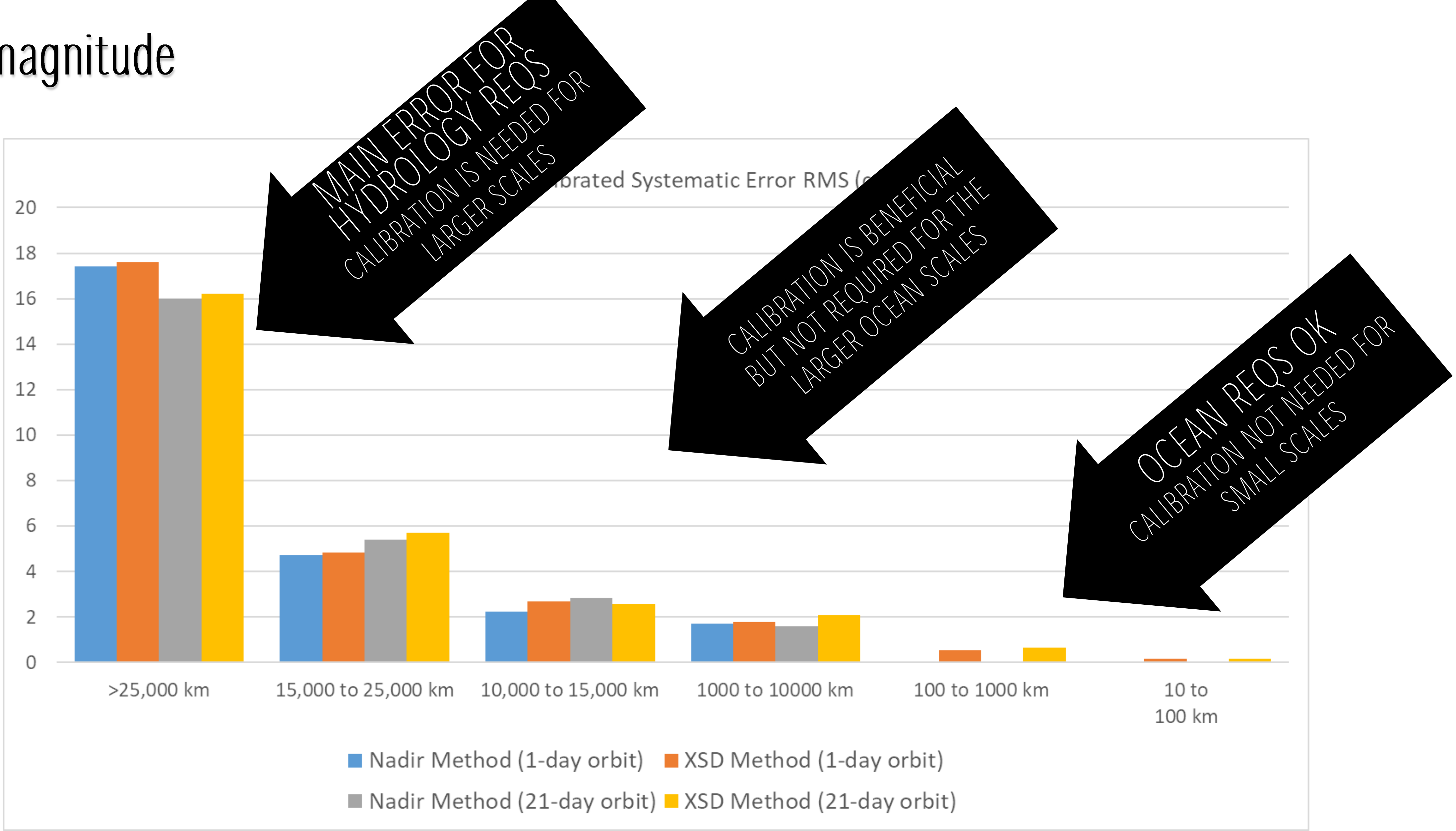




Note : actual Z scales range from millimeter-level to meter-level

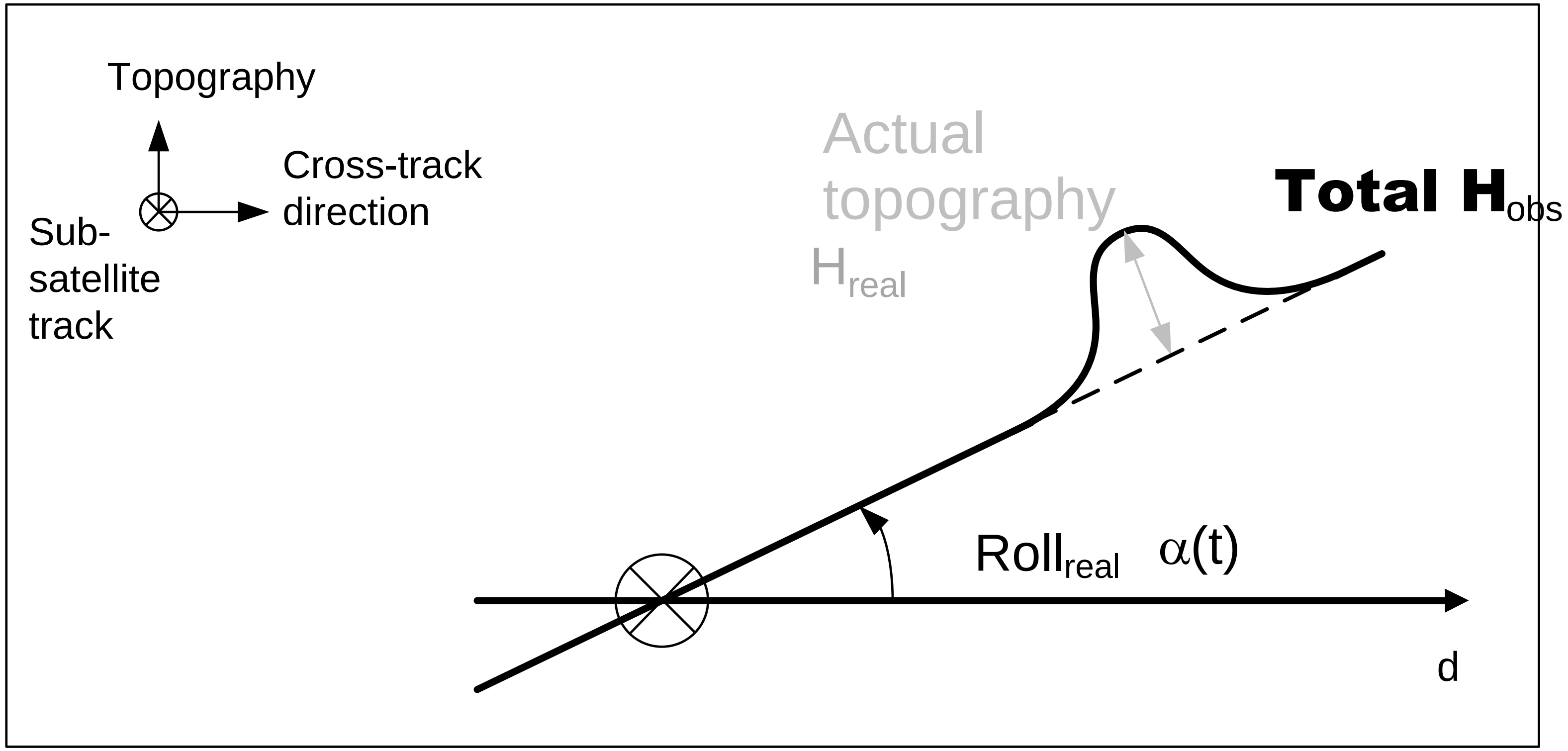
(see Project slides or poster & preprint from C.Ubelmann)

Orders of magnitude



Basic principle

Roll estimation in a nutshell



$$H_{obs} = H_{real} + \varepsilon + \alpha(t) * d$$

H_{real} is what SWOT wants to observe

a is the roll unknown

ε is the topography error (roll excluded)

d is the cross-track distance

Roll estimation in a nutshell

H_{real} is what SWOT wants to observe
a is the roll unknown
ε is the topography error (roll excluded)
d is the cross-track distance

$$H_{obs} = H_{real} + \varepsilon + \alpha(t) \, . \, d$$

Assume that $\alpha(t).d$ is orthogonal to other items

➡ Find the cross-track SSHA slope in every line of a KaRIN image

Repeat the process for other errors (bias, quadratic model…)

All flavors of data-driven calibration follow this logic with various layers of complexity

analytical models, crossovers, AI-based algorithms, massive 2Dvar inversions, model assimilation…

Limits and risks

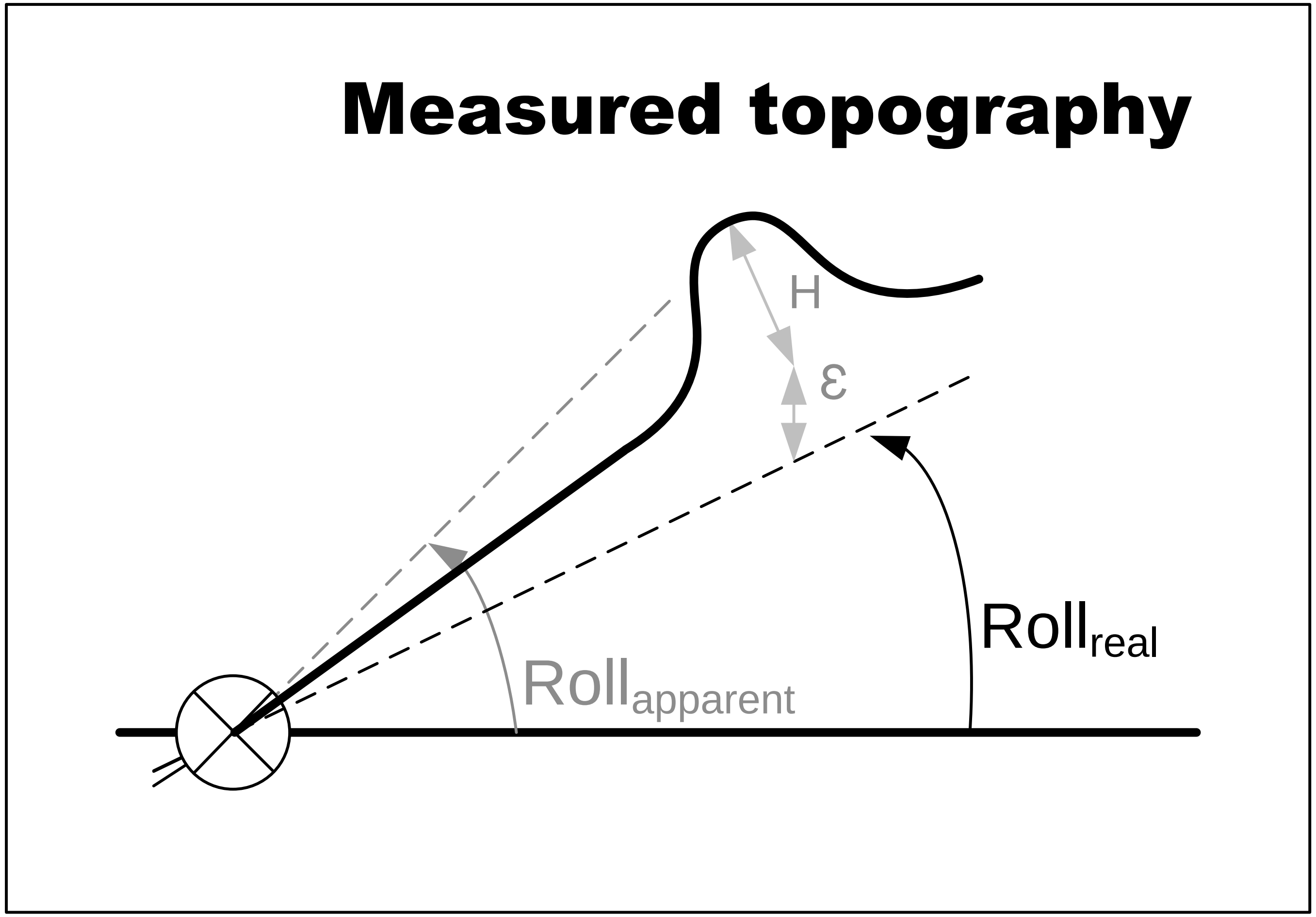
Pitfall: SWOT has a narrow field of view

- H_{real} can have a non-zero bias and cross-track slope over 120 km

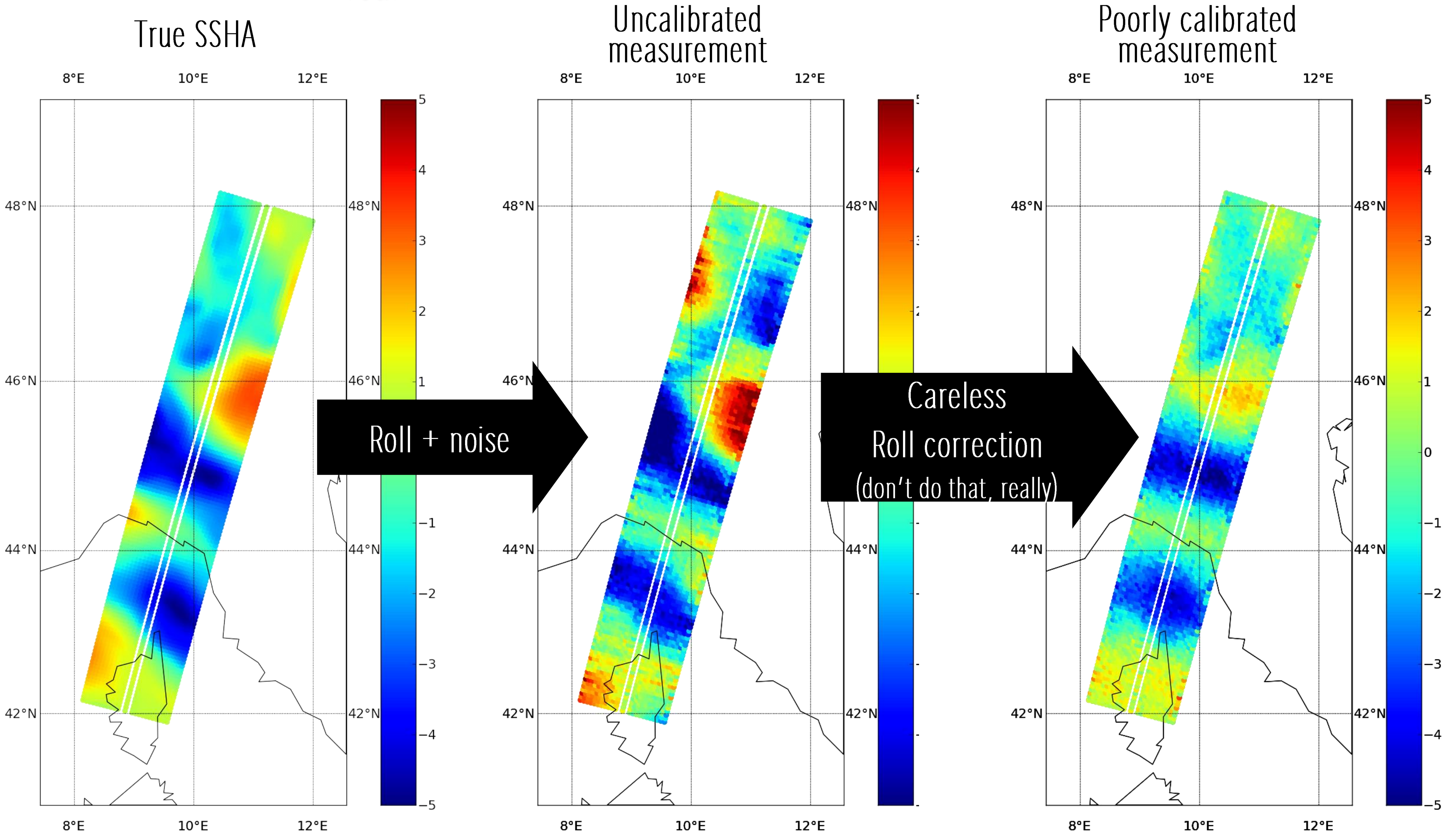
- ε can have a non-zero bias and cross-track slope over 120 km

- This fraction of H_{real} and ε will leak into the calibration correction

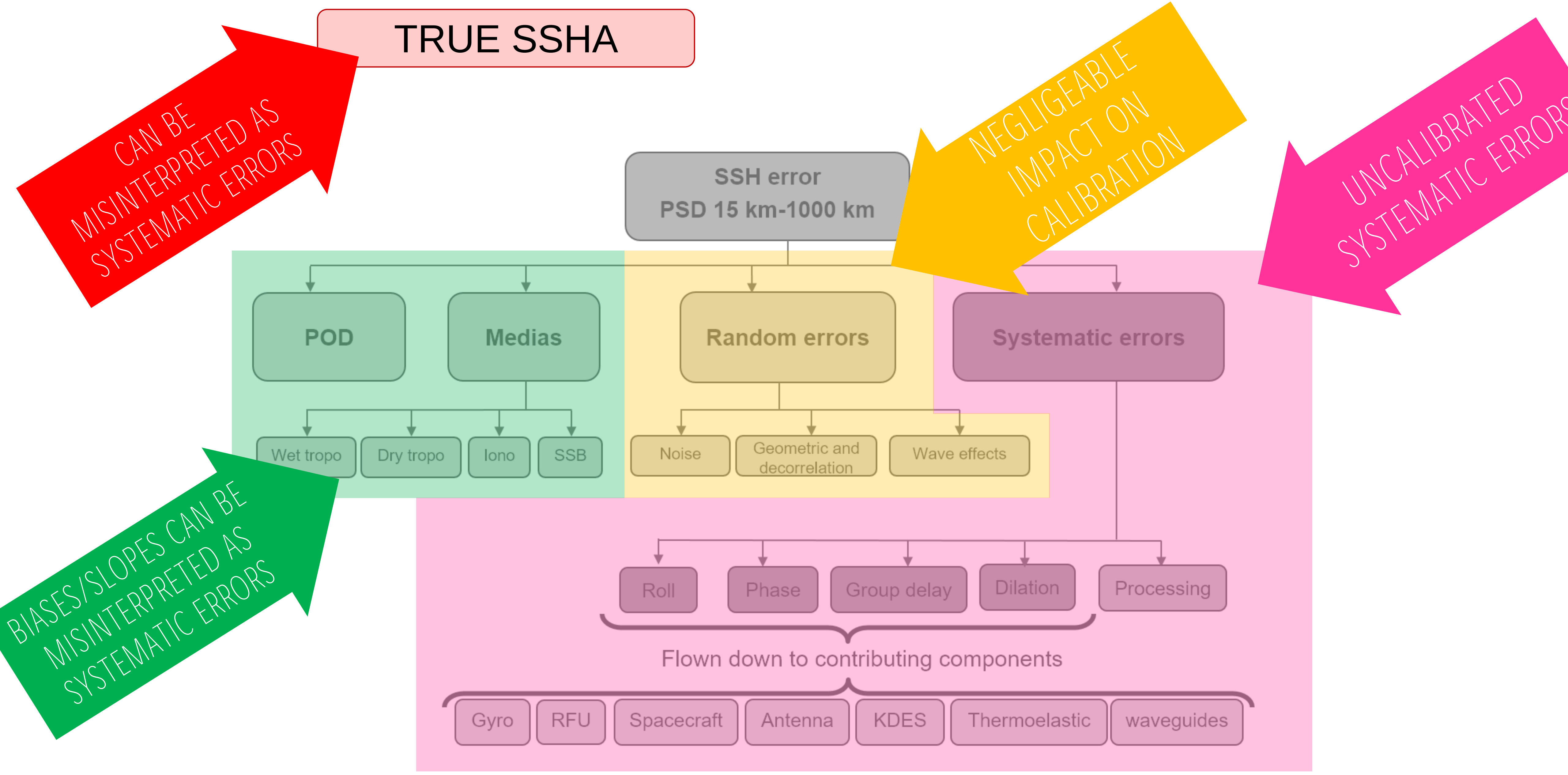
- Using the calibration correction will remove this fraction of H_{real} and ε from H_{obs}



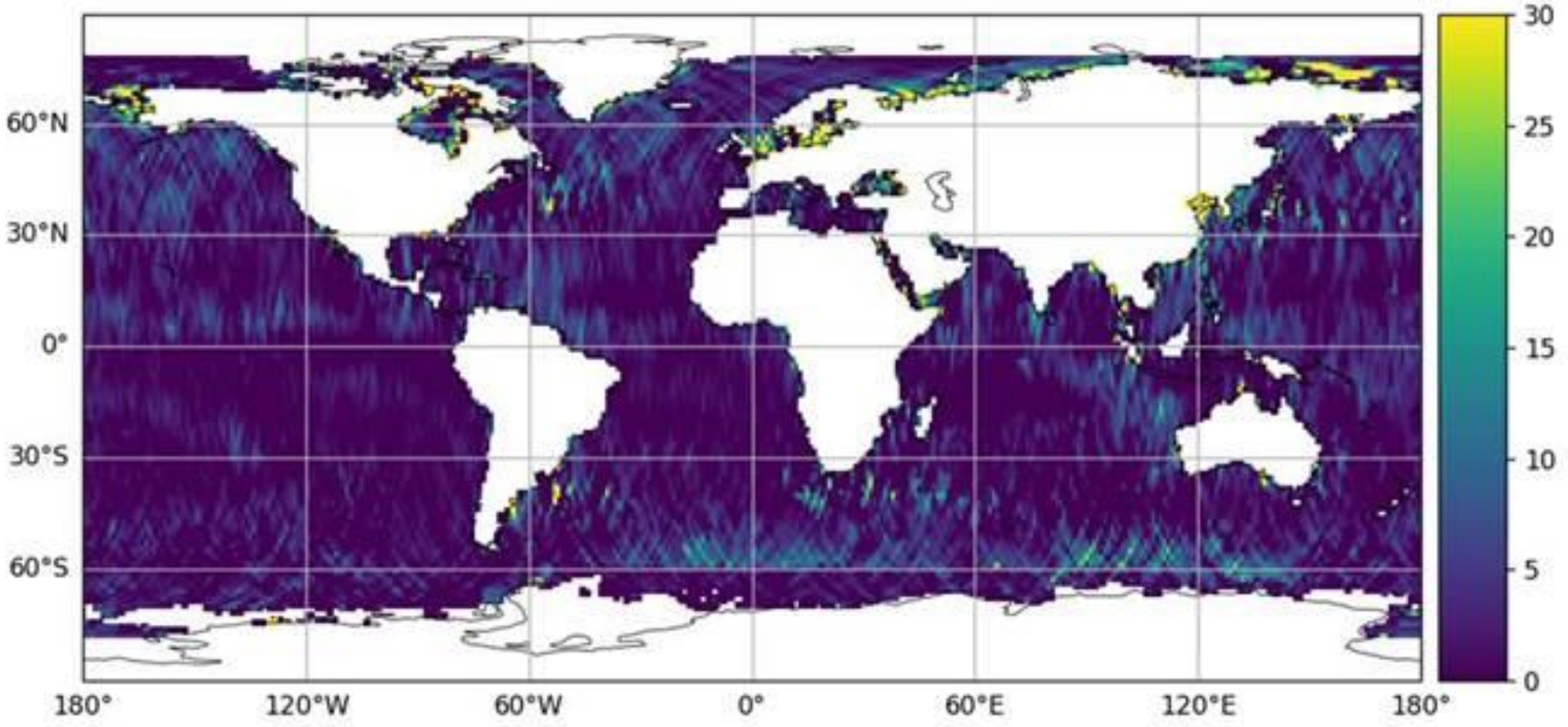
Exagerated example for H_{real} (ocean leakage from simulation)



Roll removed <u>BUT</u> all cross-track gradients from mesoscale were destroyed as well


TRUE SSHA
CAN BE MISINTERPRETED AS SYSTEMATIC ERRORS
NEGLIGEABLE IMPACT ON CALIBRATION
UNCALIBRATED SYSTEMATIC ERROR
SSH error
PSD 15 km-1000 km
POD
Medias
Random errors
Systematic errors
Wet tropo
Dry tropo
Iono
SSB
Noise
Geometric and decorrelation
Wave effects
BIASES/SLOPES CAN BE MISINTERPRETED AS SYSTEMATIC ERRORS
Roll
Phase
Group delay
Dilation
Processing
Flown down to contributing components
Gyro
RFU
Spacecraft
Antenna
KDES
Thermoelastic
waveguides

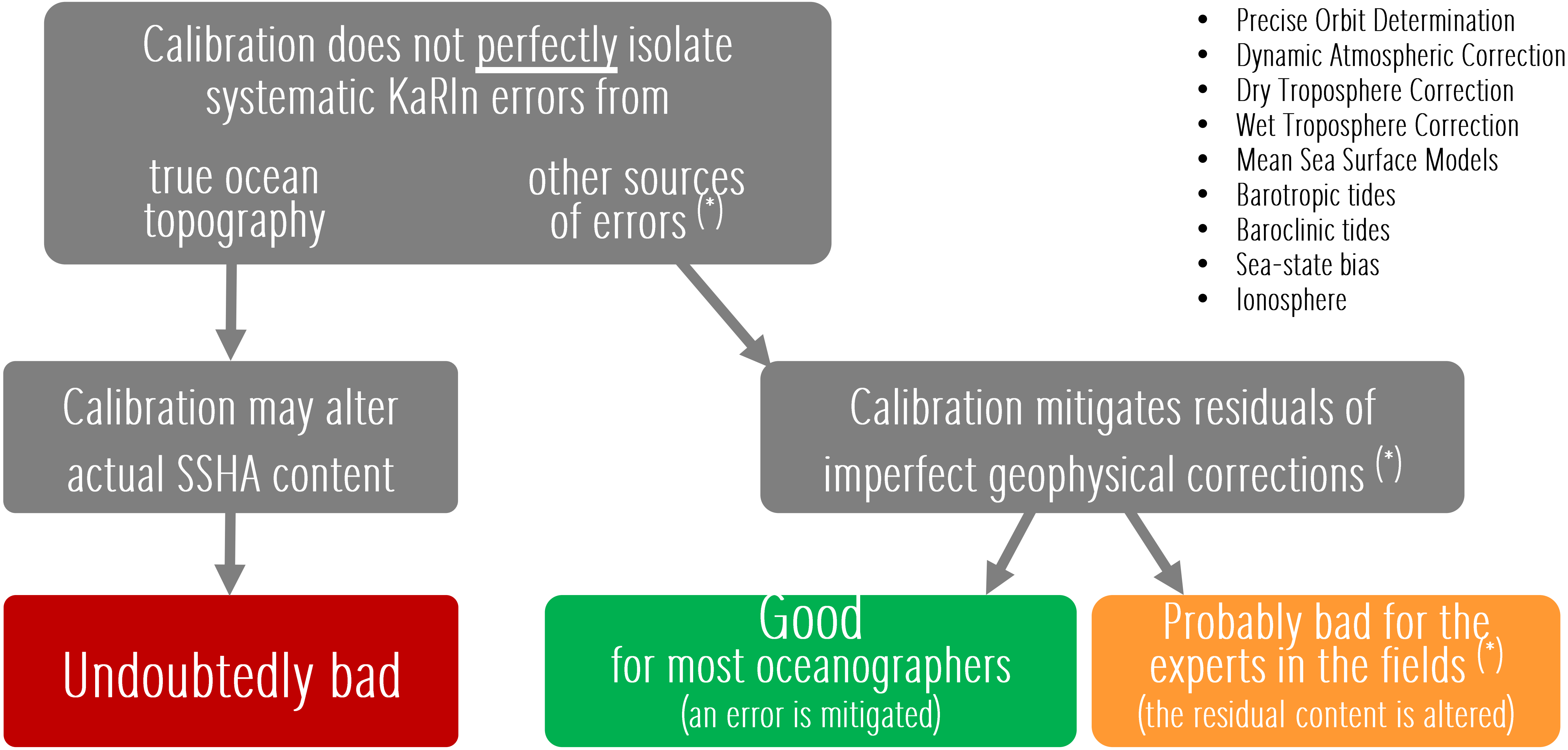
Example: large scale KaRIn/nadir variance (from Project talk)



Practical consequences

(*) list of geophysical residuals that the calibration might absorb

- Precise Orbit Determination
- Dynamic Atmospheric Correction
- Dry Troposphere Correction
- Wet Troposphere Correction
- Mean Sea Surface Models
- Barotropic tides
- Baroclinic tides
- Sea-state bias
- Ionosphere



Mitigation methods of advanced calibrations

Level-2 xovers

Level-3 multimission

1. Use image-to-image difference to cancel out slow ocean/geophysics variability
2. Use external H_{real} first guess from nadir altimeter(s) to cancel out large scale variability
3. Use statistical knowledge of oceanic variability spectrum / covariance
4. Use statistical knowledge of uncalibrated errors
5. Use a low-pass cut-off when calibration is no longer needed

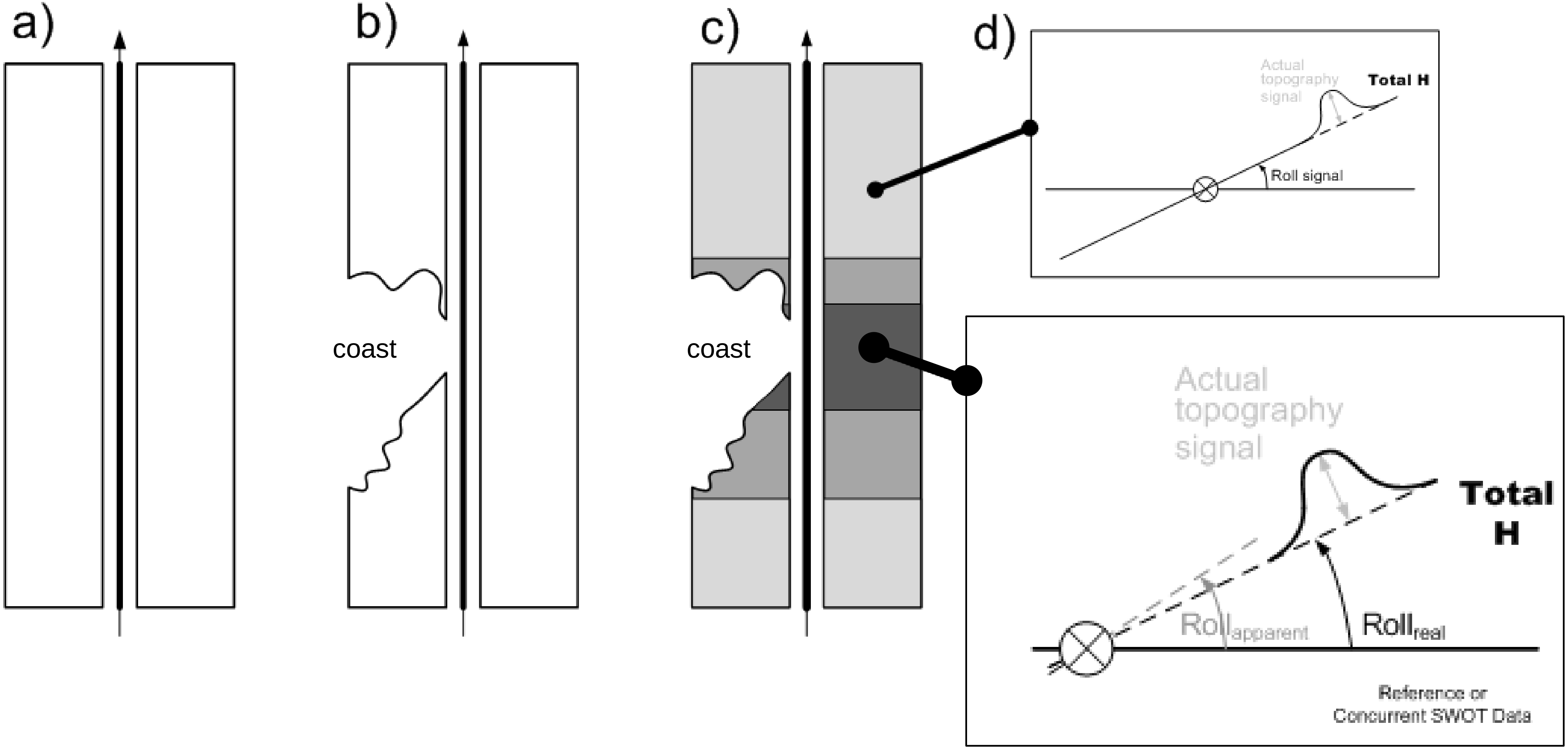
Level-3 research grade
« optimal » inversions

If the mitigation works, the advanced calibration is less prone to leakage

These mitigations work as expected for the SSHA

Cal/Val results show the L2/L3 calibrations are indeed absorbing a fraction of "geophysical errors"

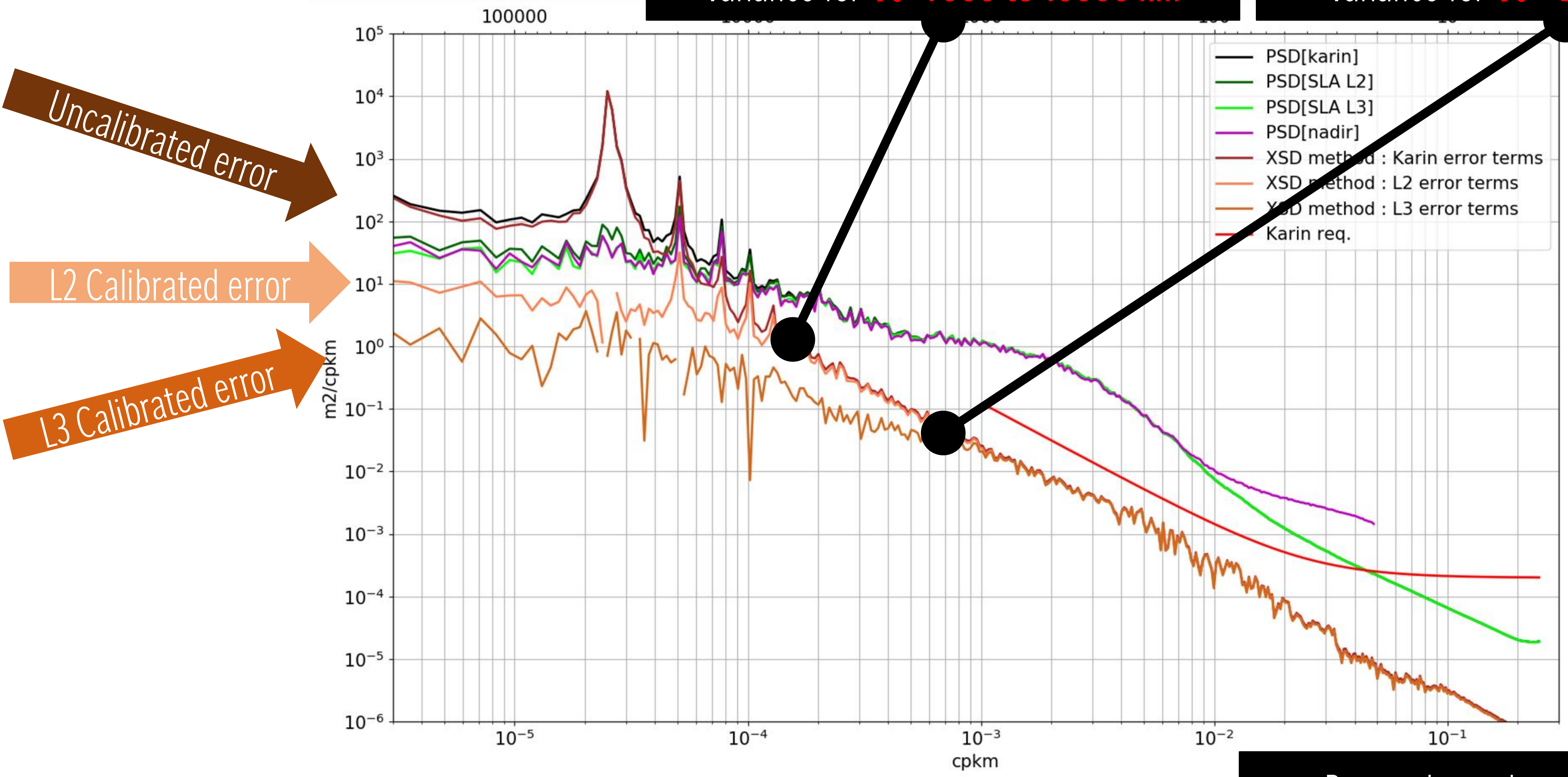
The hardcore calibration challenge: coastal zones and sea-ice



Calibration figures of interest

L2 calibration reduces the SSHA error variance for λ>7000 to 10000 km

L3 calibration reduces the SSHA error variance for λ> 2000 to 3000 km



PHASE E1

NRT/FWD PRODUCTS

Research-grade calibration can be customized for specific studies

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L2/L3 calibrations are absorbing a fraction of "geophysical errors"

Good for most users

Maybe bad for experts of geophysical models

The link is complex to explore

It requires a collaborative analysis from various fields and experts from the ST

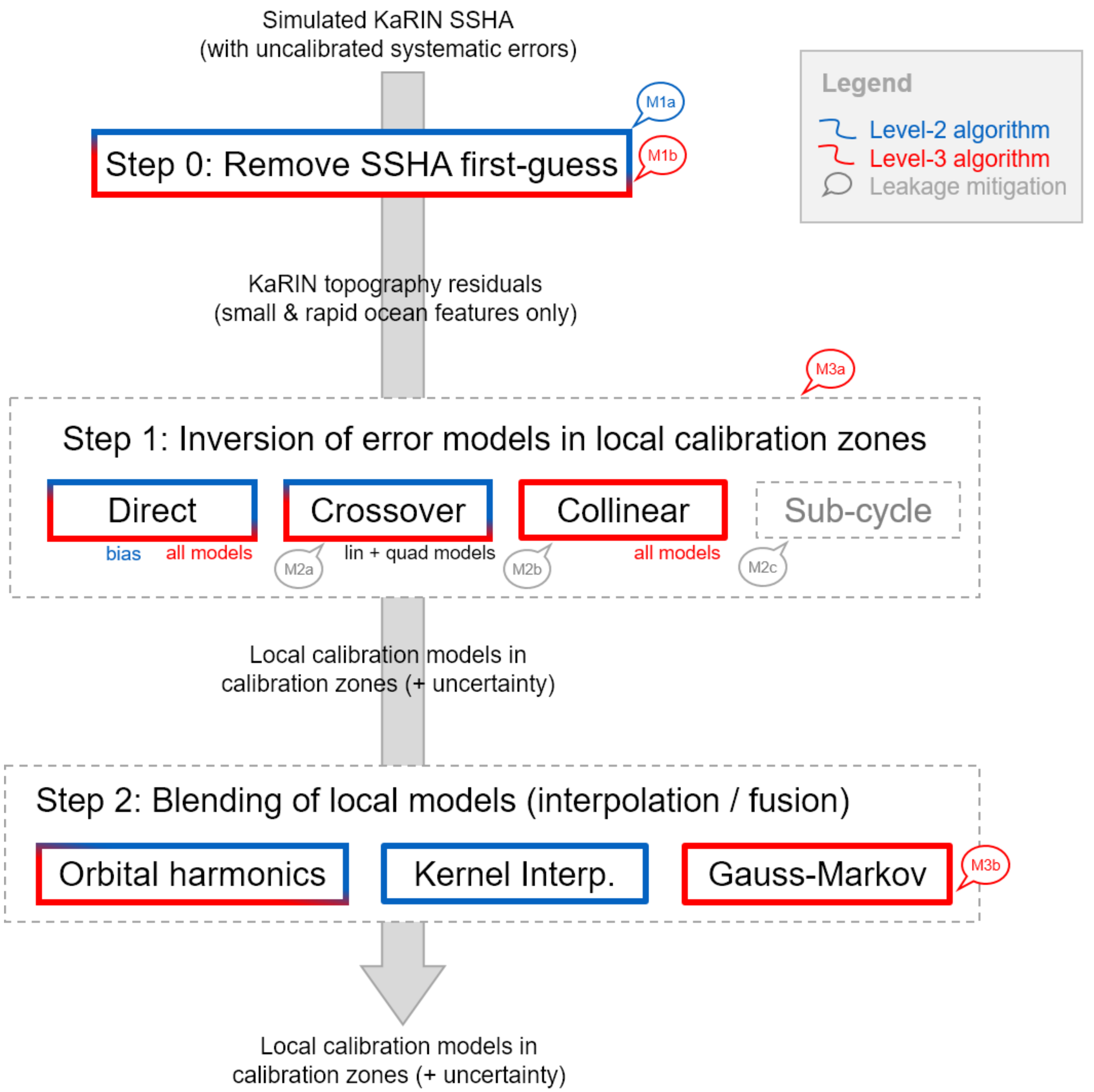
(empirical calibration & geophysical experts)

cnes CLS datlas

BACKUP SLIDES

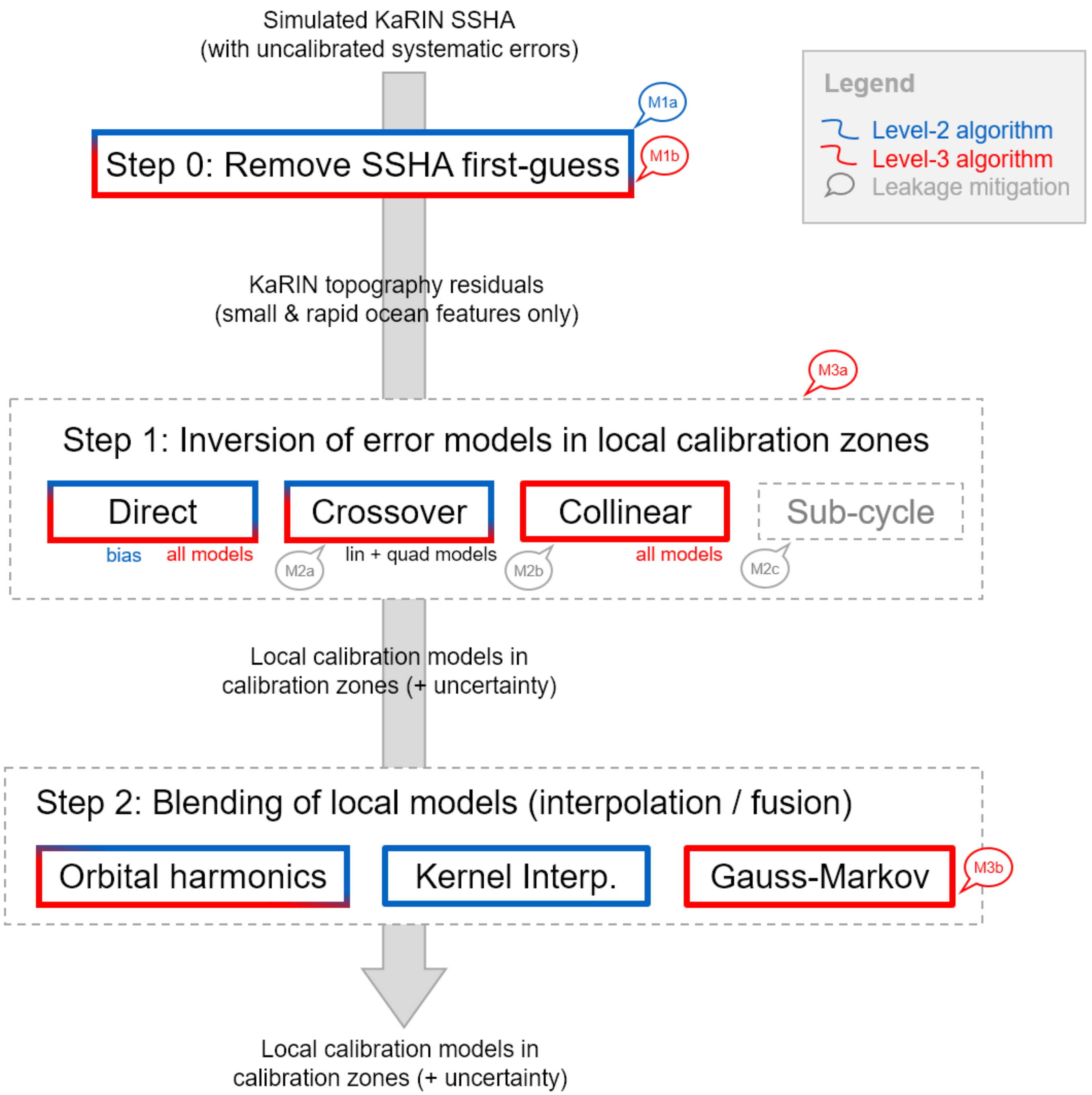
Level-2 data-driven calibration (blue items)

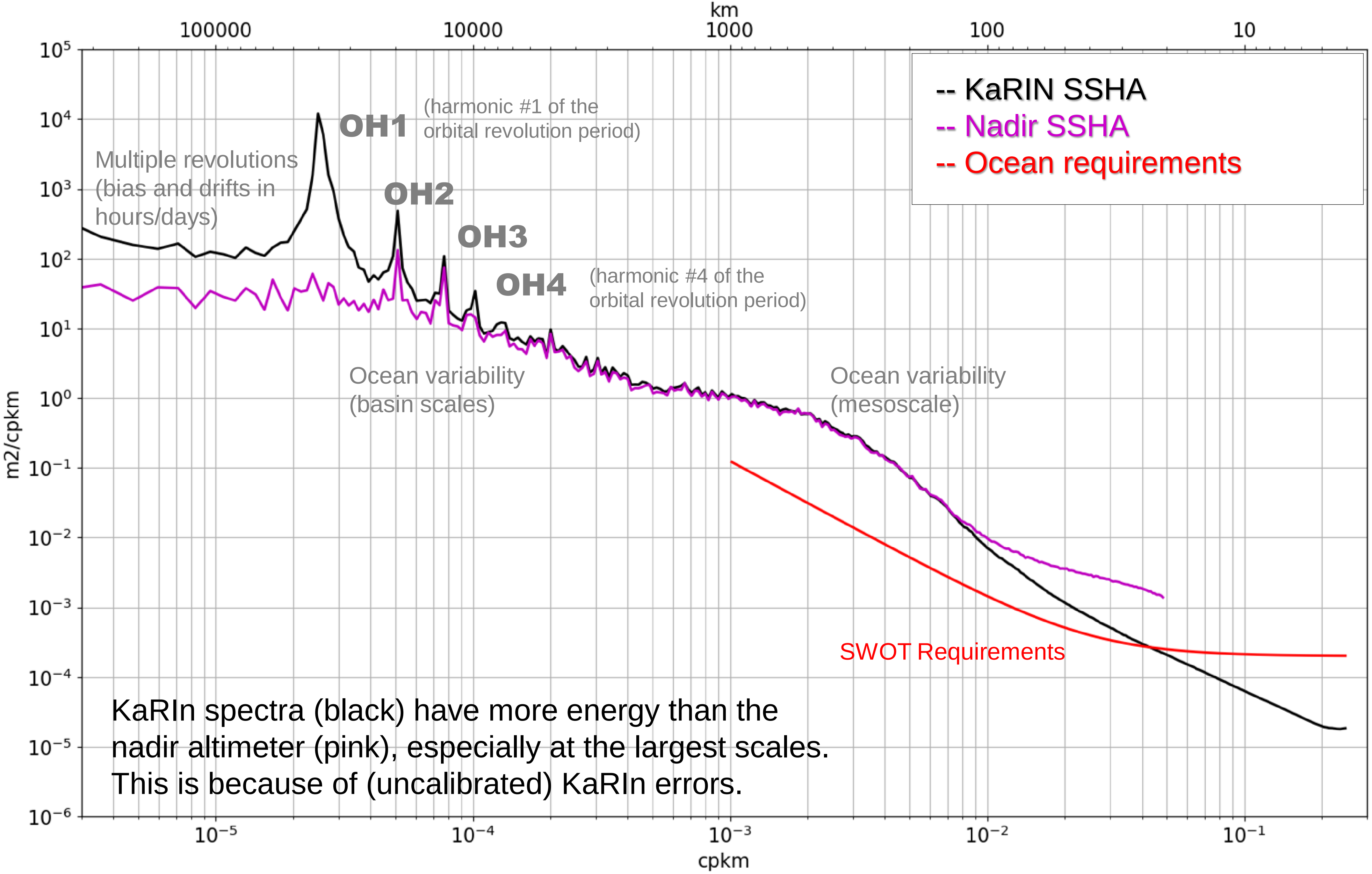
- Step 0 & M1a: use SWOT altimeter only (SWOT must be self-sufficient)
- Step 1: use Direct for bias (w.r.t to nadir) and Crossover for other error components. Inversions done with least squares (robustness)
- Step 2: harmonic interpolator for for repeating error patterns (orbital revolution period and sub-harmonics)
- Step 2: weighted kernel smoother for broadband residual (robustness)
- The L2 sequence does not require any complex parameter (no covariance, no spectra, etc.) for the sake of robustness and simplicity

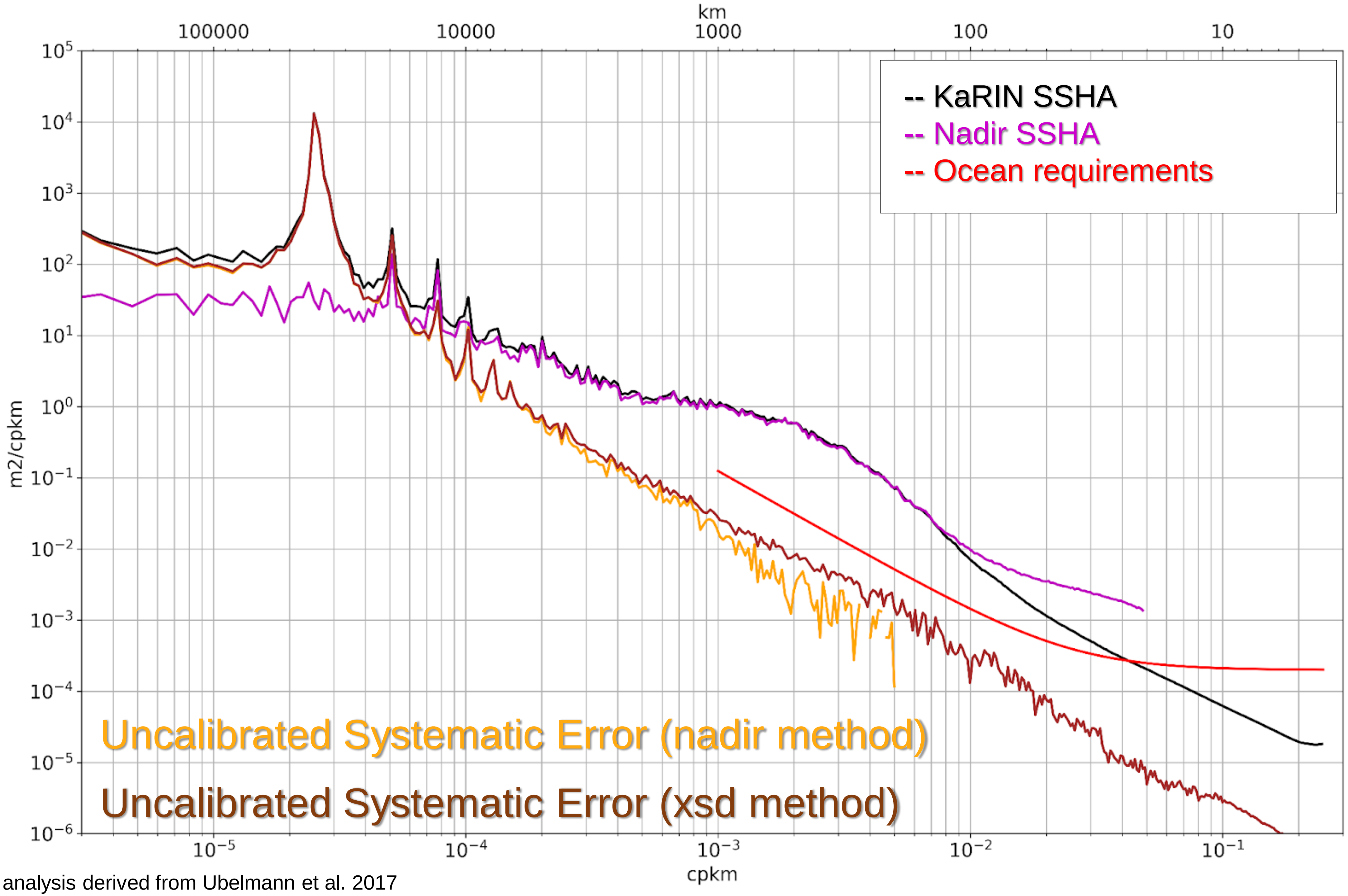


Level-3 data-driven calibration (red items)

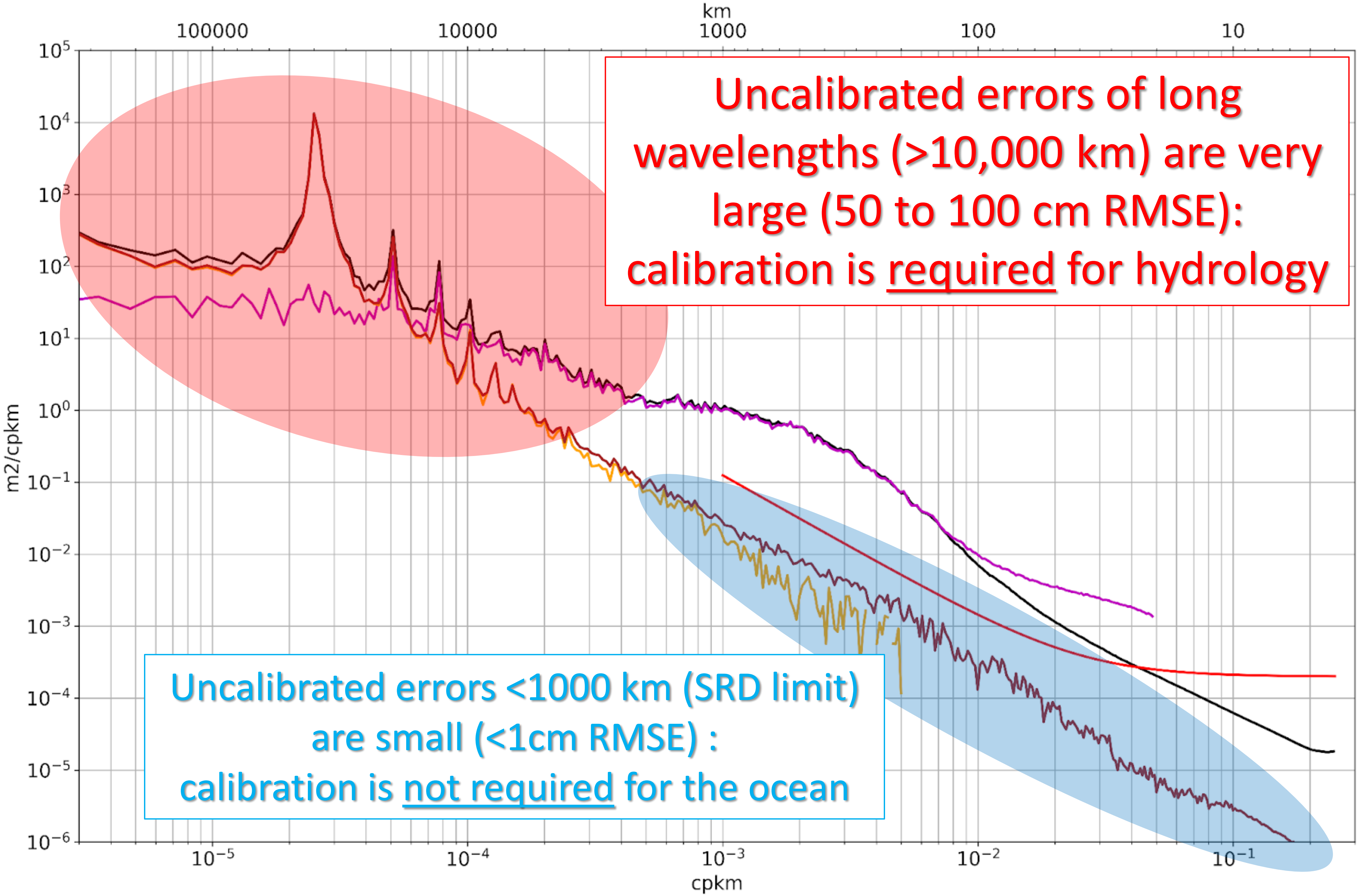
- Step 0 & M1b: external data from all nadir altimeters (SWOT + S6 + S3)
- Step 1: use Direct and Crossover retrieval algorithms for the 21-day orbit, and Direct + Collinear for the 1-day orbit
- Step 1: Can resolve intra-crossover variability (not just a scalar/xover)
- Step 2: use Gauss-Markov interpolator for broadband error (not a simple kernel interpolator)
- M3a & M3b: use covariance/spectra instead of least squares (measured in simulation, determined in CalVal for flight data)




km
100000
10000
1000
100
10
-- KaRIN SSHA
-- Nadir SSHA
-- Ocean requirements
OH1
(harmonic #1 of the orbital revolution period)
Multiple revolutions (bias and drifts in hours/days)
OH2
OH3
OH4
(harmonic #4 of the orbital revolution period)
Ocean variability (basin scales)
Ocean variability (mesoscale)
SWOT Requirements
KaRIn spectra (black) have more energy than the nadir altimeter (pink), especially at the largest scales. This is because of (uncalibrated) KaRIn errors.
m2/cpkm
cpkm



Flight data analysis derived from Ubelmann et al. 2017



km
100000
10000
1000
100
10
m2/cpkm
cpkm
Uncalibrated errors of long wavelengths (>10,000 km) are very large (50 to 100 cm RMSE): calibration is required for hydrology
Uncalibrated errors <1000 km (SRD limit) are small (<1cm RMSE) : calibration is not required for the ocean