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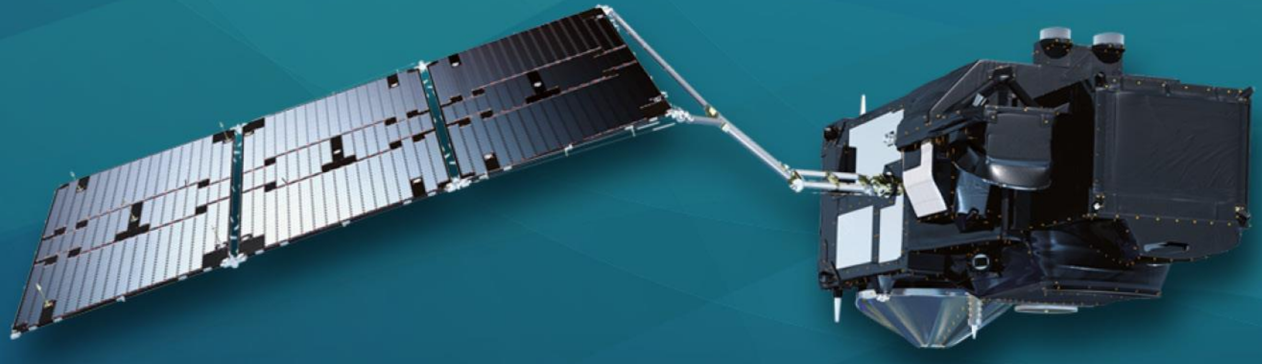


9th Sentinel-3 Validation Team meeting 2026

30 March–01 April 2026 | ESA–ESRIN | Frascati (Rome), Italy

Uncertainty Estimation for Sentinel-3 ice sheet elevation measurements

Karla Boxall[1], Mal McMillan[1]

UK Centre for Polar Observation and Modelling, Centre of Excellence in Environmental Data Science, Lancaster University

1. Motivation

- Sentinel-3 represents a valuable tool for advancing ice sheet research
  - Monitoring ice sheet **mass balance**
  - Estimating **sea-level rise** contribution of the ice sheets
  - Understanding the **climate processes** that drive ice sheet change

- Benefits of Sentinel-3 for ice sheet research:
  - Frequent **temporal repeat** sampling
  - 'Global' **SAR** coverage
  - Guaranteed **long-term continuity** of an operational mission
    - → critical for building a long-term climate record

1. Motivation

- Sentinel-3 represents a valuable tool for advancing ice sheet research

- Well-constrained **uncertainties** are required to **maximise the potential** of Sentinel-3 for ice sheet research:
  - Quantifying associated certainty on **mass balance and sea level** rise estimates
  - Development and validation of numerical **models**
  - Developing systems that can **integrate parallel data** streams

- No **standardised approach** to uncertainty generation currently exists
- No **method to evaluate uncertainty** robustness currently exists

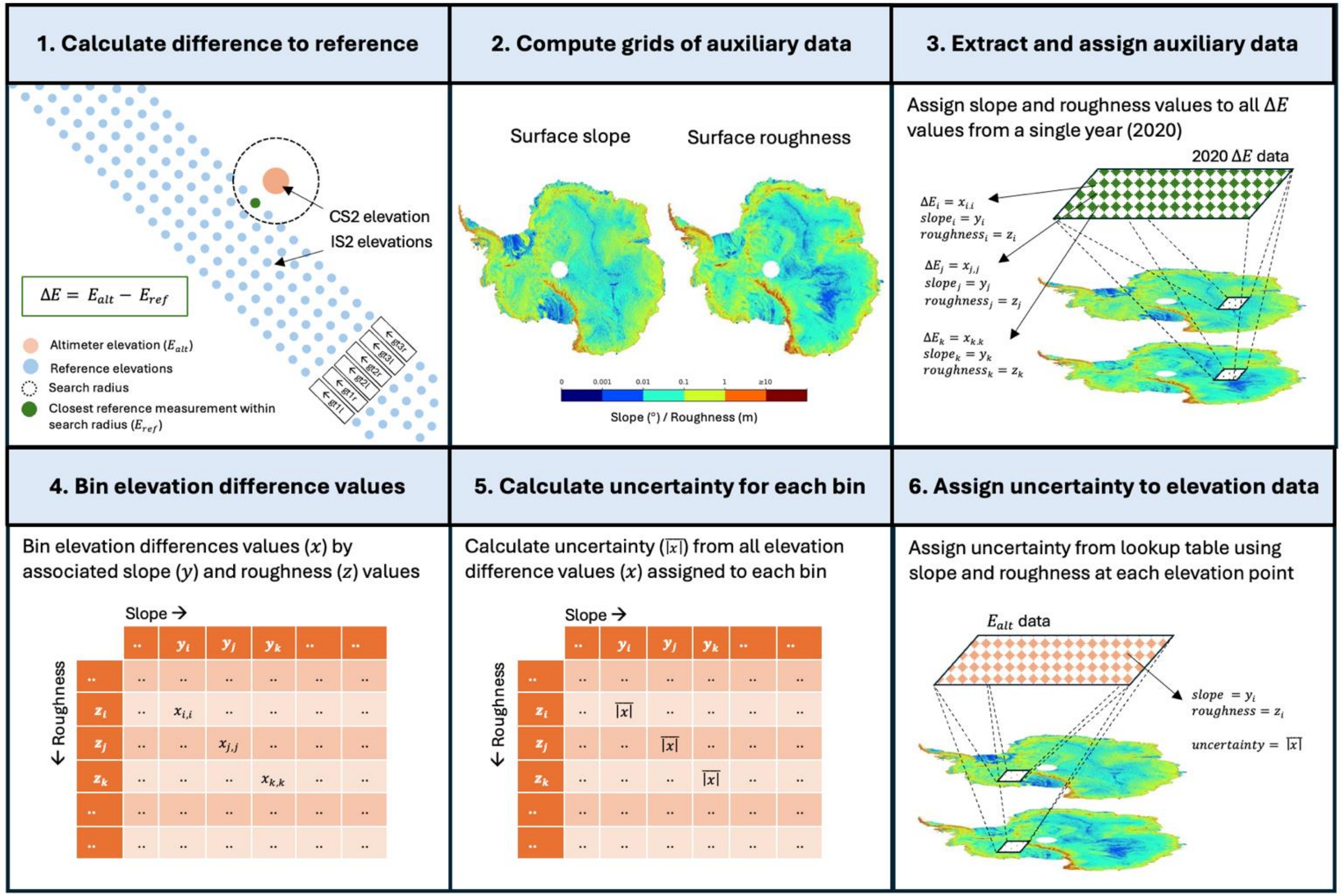
➢ **R&D: Uses validation of S3 measurements (comparison to reference measurements) to generate and assess new S3 uncertainties**

Uncertainty generation framework

a) Generate
b) Assess

uncertainties for Sentinel-3 BC005 land ice product

Empirical parameterisation of validation results



Uncertainty evaluation framework

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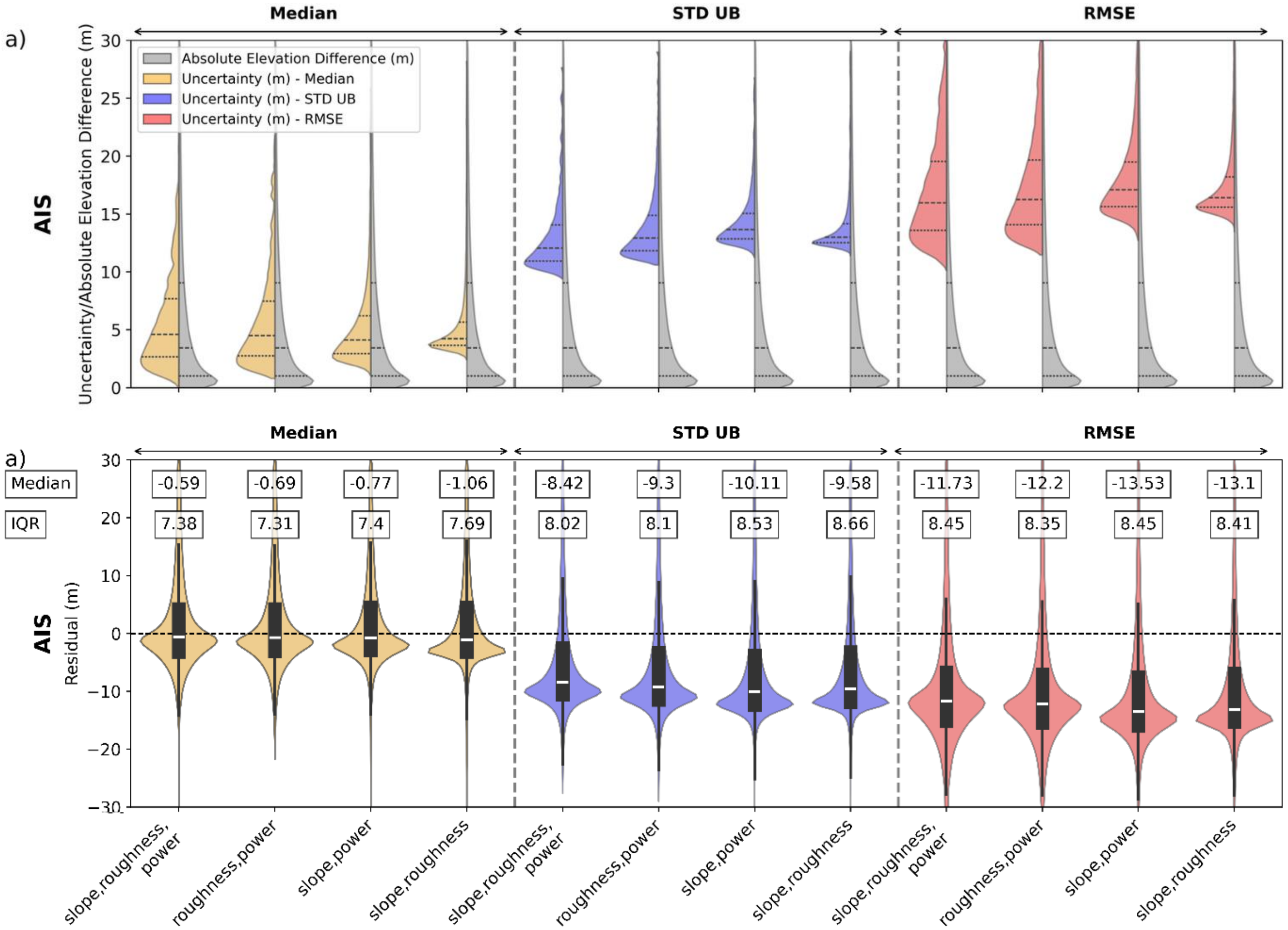
CLEV²ER:
Land Ice & Inland Water

a) Generate

b) Assess

uncertainties for Sentinel-3 BC005 land ice product

Comparison of uncertainties to unseen validation results



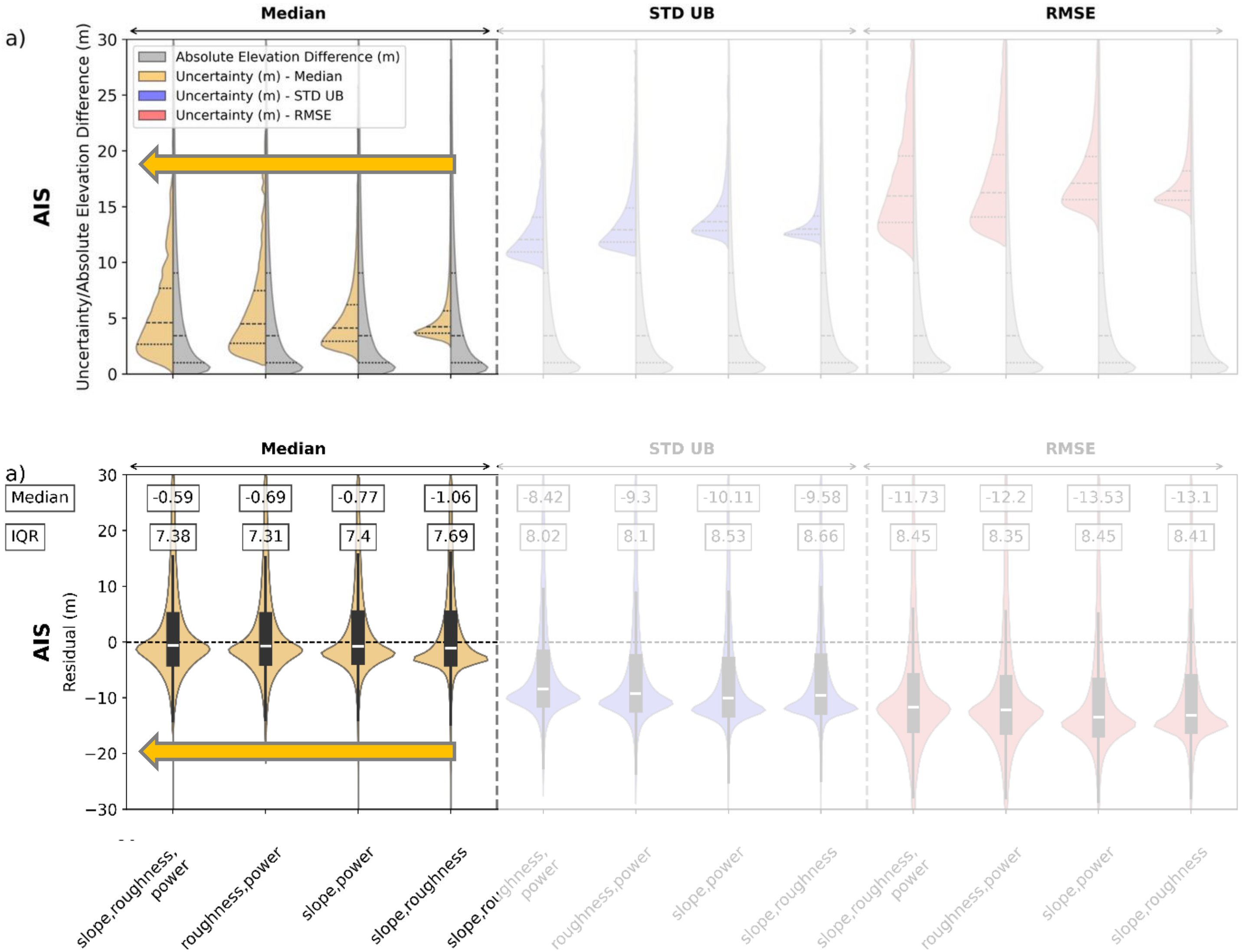
3. Results

- High dimensional lookup table
- Populated using the median

often produces the **most robust** set of uncertainties for Sentinel-3

Median metric → most robust uncertainties

Higher dimensionality → most robust uncertainties



3. Results

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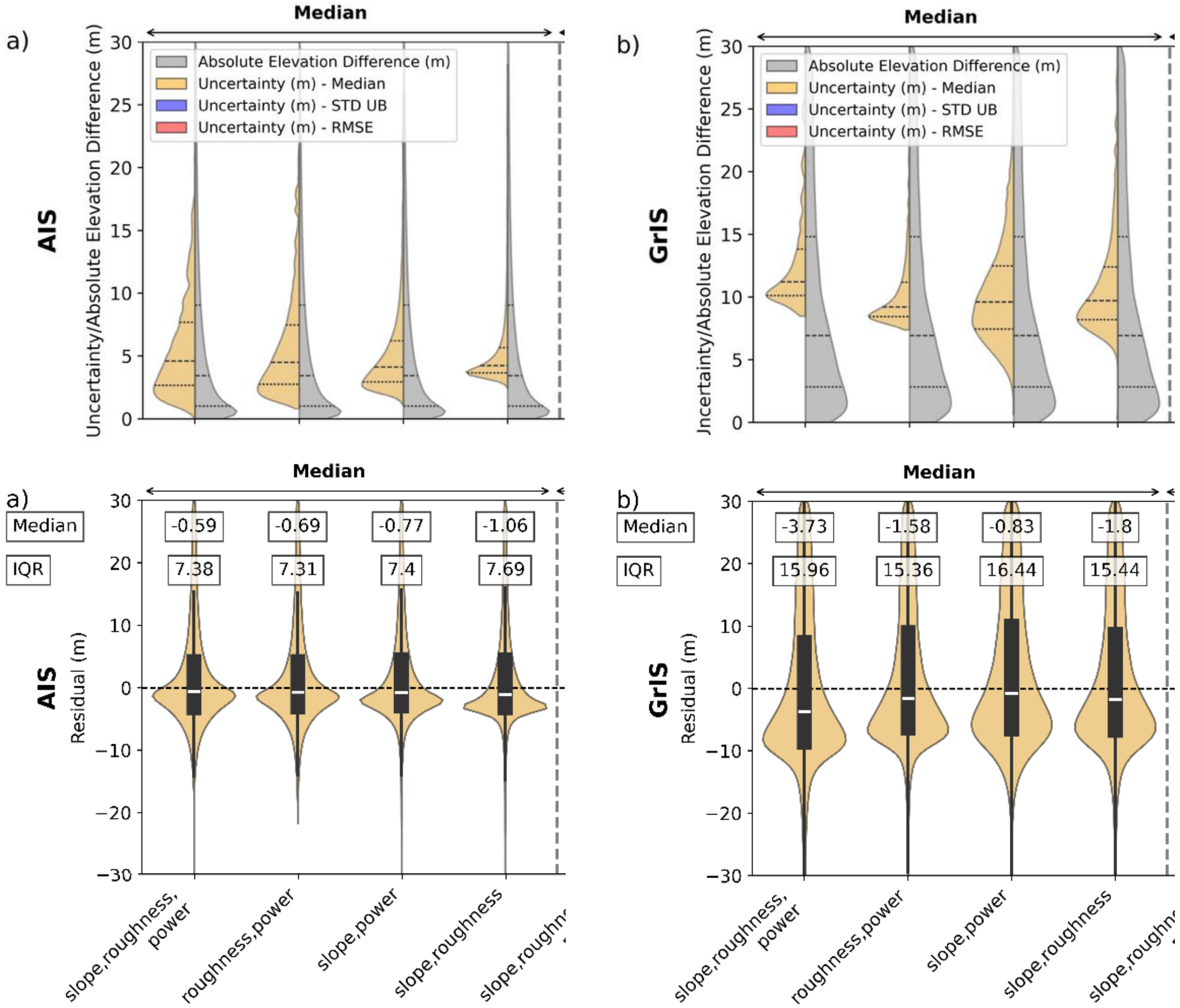
- Region of interest

affects the robustness of uncertainties

Different data volume and topographical complexity associated with each region

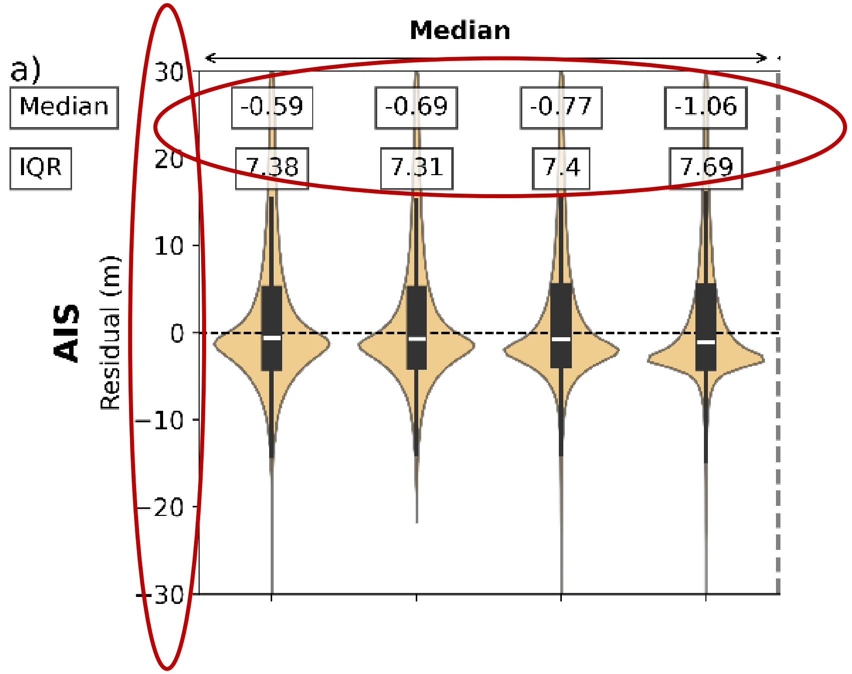
Antarctica | **Greenland**



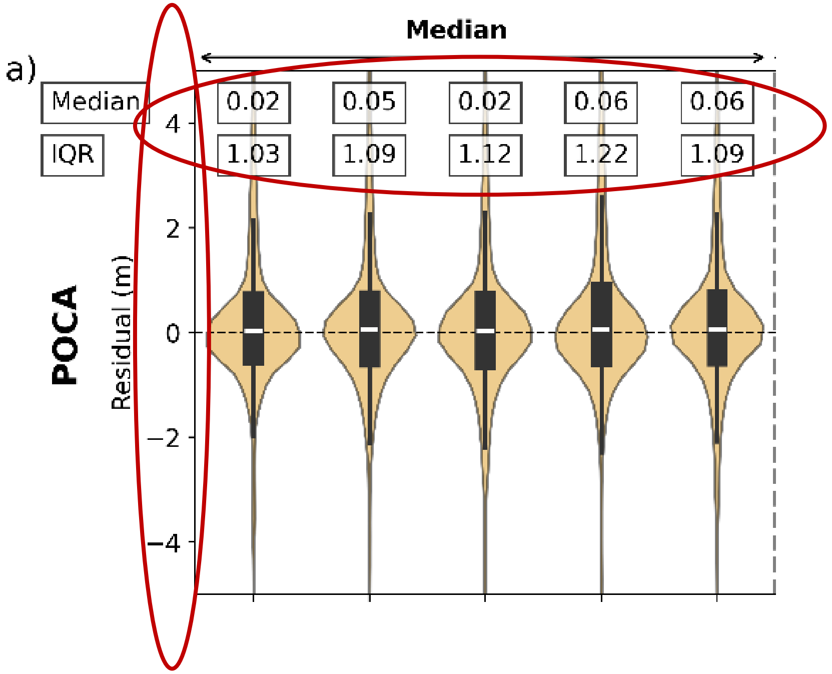
4. Implications

Comparison to CS2 uncertainties

S3



CS2



- S3 uncertainties overestimate compared to the accuracy of CS2 uncertainties
- These initial S3 values = maximum uncertainties

→ key for the effective interpretation and application of these new uncertainties by potential users

- **Long-term aim**: apply the framework to all missions (historical and future e.g. CRISTAL, S3 Next Generation)

4. Implications

Combination with coincident missions

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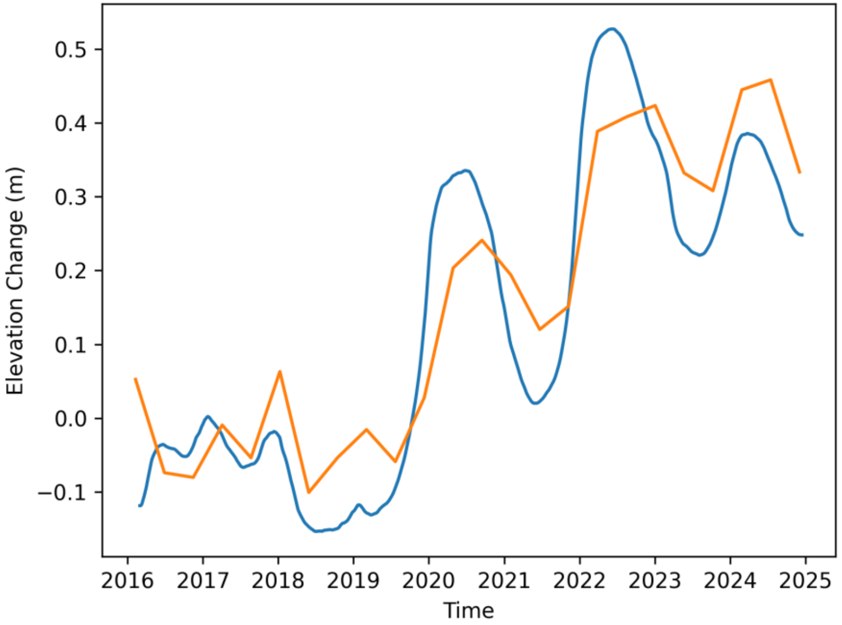
- Consistent uncertainty estimations is crucial for combining data (S3A/B/C, S3/CS2, thematic/AMPLI)

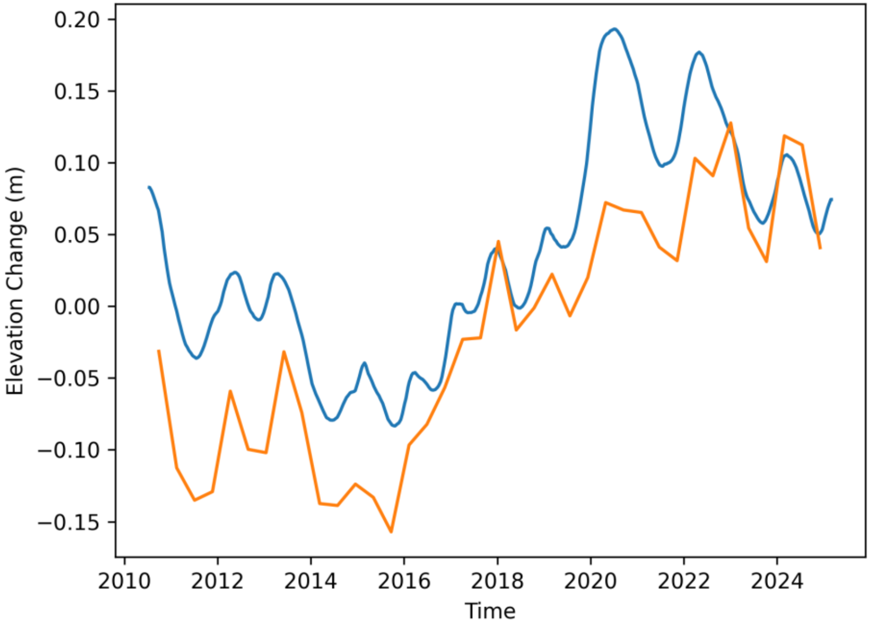
➢ Kalman Filtering

Cook E2 basin,
SARIn region

S3A thematic Kalman Filter
S3 thematic surface fit



CS2 Cryo-TEMPO Kalman Filter
CS2 Cryo-TEMPO surface fit

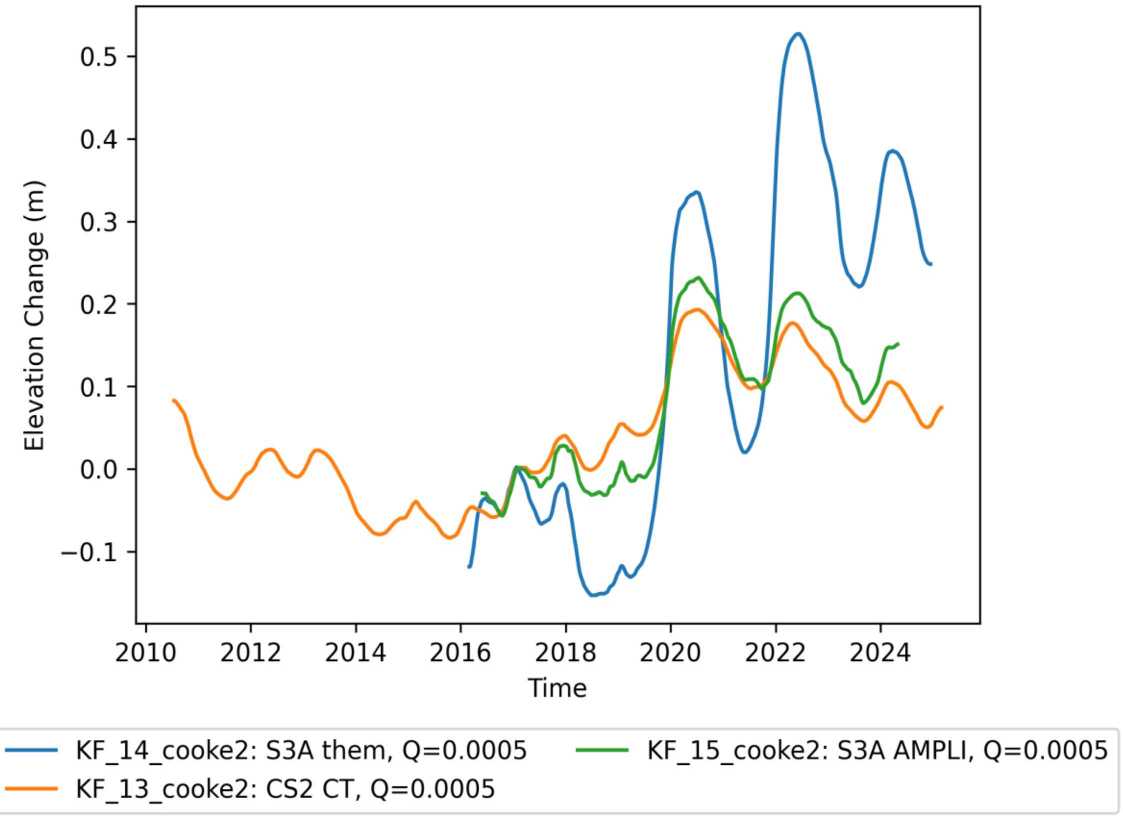


Combination with coincident missions

- Consistent uncertainty estimations is crucial for combining data (S3A/B/C, S3/CS2, thematic/AMPLI)

➢ Kalman Filtering

S3A thematic Kalman Filter
CS2 Cryo-TEMPO Kalman Filter
S3A AMPLI Kalman Filter



5. Summary

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https://doi.org/10.5194/egusphere-2026-556

Framework developed to:

1. generate and
2. assess S3 uncertainties

Recommendations

- **Inclusion of uncertainties** key to maximising use of S3 data in ice sheet research:
  - Certainty of mass balance estimations, SLR contributions, numerical modelling
  - Integrating parallel data streams (i.e. combining data from coincident missions)
- **Robust uncertainty** generation method:
  - Empirical parameterisation of elevation difference to reference measurement
  - High-dimensional lookup table populated using the median (but regional variability)

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Preprint. Discussion started: 17 March 2026

EGUsphere Preprint repository

A framework for evaluating ice sheet altimetry uncertainty estimates

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Abstract. For three decades, ice sheet elevation records from satellite radar altimetry have provided new insight into the state of the cryosphere and its contribution to global sea-level rise. The availability of robust, consistent and traceable uncertainties alongside ice sheet elevation data is crucial for combining measurements across missions and enabling their use in reconciling estimates of ice sheet mass balance and constraining numerical ice sheet models. At present, such uncertainties are largely absent from existing Level 2 ice sheet elevation products, and for the subset of products where uncertainties are provided, there is neither a standardised approach to uncertainty generation nor a method to evaluate their robustness. Here, we develop a novel uncertainty evaluation framework and provide a comprehensive assessment of uncertainty generation for altimetry-based ice sheet elevations. Overall, we find that calculating uncertainty as a parameterisation of topographic complexity (characterised by surface slope and roughness) and measurement quality (characterised by backscattered power and coherence) improves performance relative to solutions that use fewer co-variates. Ultimately, the framework presented here will enable the systematic characterisation of ice sheet elevation uncertainties associated with historical, current and future polar radar altimeter missions, including the Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL). Such information will aid the successful combination of altimetry measurements across missions, improve the constraint of numerical ice sheet models, and enable more certain estimates of current and future ice sheet mass balance and global sea-level rise.