Deutsches Geodätisches Forschungsinstitut
TUM School of Engineering and Design
Technische Universität München

IRIS: Global River Surface Slopes from ICESat-2 and its Contribution to SWOT

Daniel Scherer (daniel.scherer@tum.de), Christian Schwatke, Denise Dettmering, and Florian Seitz

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM), Technische Universität München, Arcisstraße 21, 80333 München

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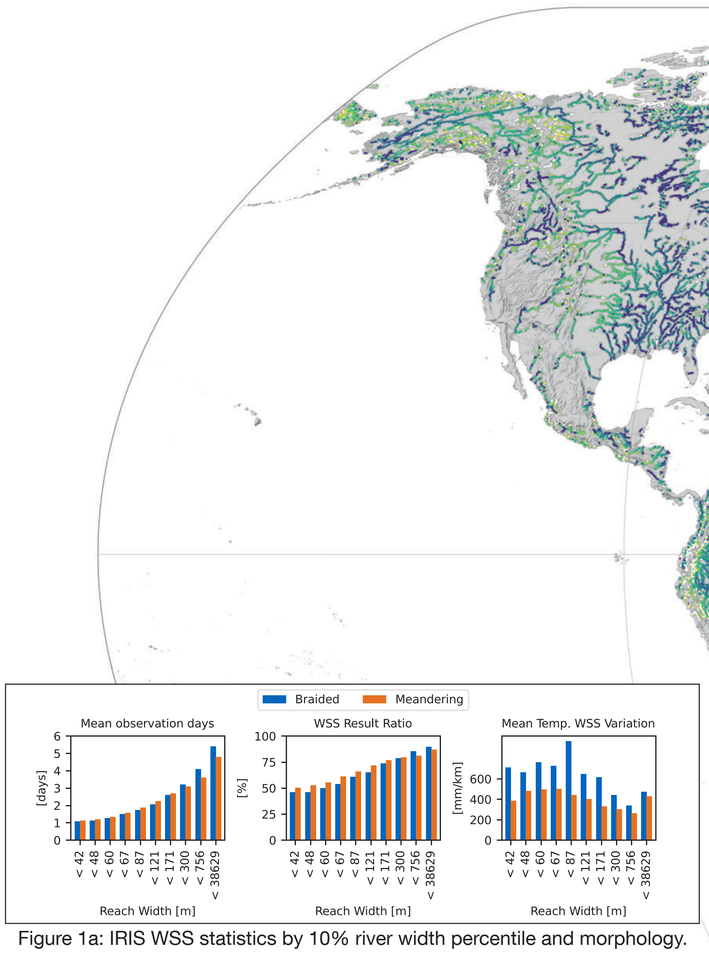

Figure 1a: IRIS WSS statistics by 10% river width percentile and morphology.

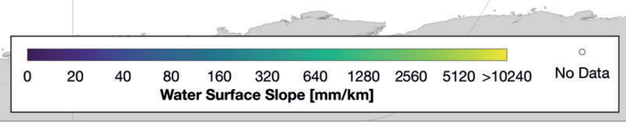

Figure 1: IRIS averaged combined water surface slope (WSS).

Introduction

The SWOT and ICESat-2 missions are both capable of measuring the Water Surface Slope (WSS), which is required to calculate river discharge, one of the Essential Climate Variables (ECV) as defined by the Global Climate Observing System. WSS is also useful for correcting water level time series from satellite altimetry for the ground track shift bias (up to 66% RMSE improvement in Scherer et al., 2022).

The ICESat-2 satellite carries a unique sensor with six parallel lidar beams that can measure water surface elevation with high precision and accuracy. The ICESat-2 mission was launched about four years before SWOT and already provides five years of data. We derive the "ICESat-2 River Surface Slope" (IRIS, Scherer et al., 2023) dataset comprising global reach-scale average and extreme WSS and **using the "SWOT Mission River Database" (SWORD, Altenau et al., 2021) as reference** so it can be easily combined, extended, or compared with SWOT observations.

The latest Version 2.0 of IRIS is based on ICESat-2 observations between October 2018 and April 2023 as a supplement to 127,666 reaches from the SWORD Database (Version 15). We will update IRIS continuously with new ICESat-2 cycles and new releases of SWORD.

Methodology

To gain full advantage of ICESat-2's unique measurement geometry with six parallel lidar beams, the WSS is determined using two approaches (cf. Figure 2 and 3):
In the (1) **across-track approach**, we calculate the WSS using the position and elevation differences of two intersections between the beams and the river centerline.
To use the (2) **along-track approach**, a single intersection of a beam and the centerline is sufficient. The along-track WSS is estimated by fitting a linear regression to the ICESat-2 water surface elevation measurements and projecting the resulting slope onto the river centerline to correct for the angle of intersection. Figure 4 shows the angle-depended outlier threshold (black line) for outlier rejection based on confidence of fitting the linear regression.

The instantaneous results of the two approaches are resampled to daily weighted averages and then combined while the along-track results are used only as a supplement to the across-track approach which is more robust. In this way, we maximize the temporal and spatial coverage.
The methodology used to derive IRIS is described in detail in *Scherer et al. (2022).*

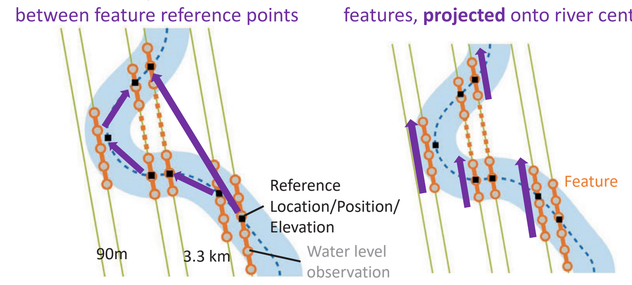

Figure 2: Schema of the Across- and Along-Track approach.

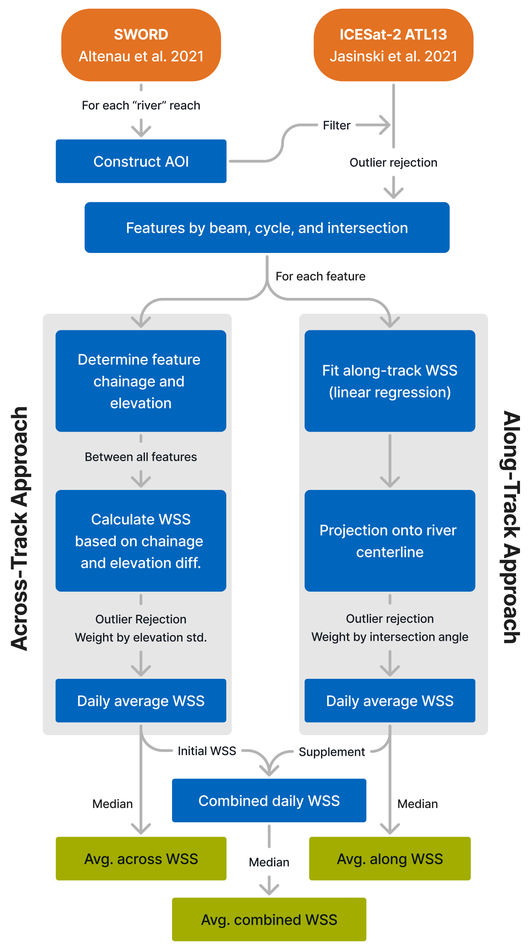

Figure 3: Processing strategy for the computation of the IRIS data.

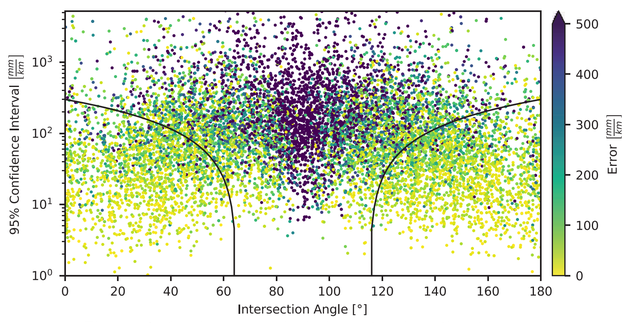

Figure 4: Angle-depended along-track outlier threshold.

Results and Validation

The main variable of IRIS is the median of the combined results of the two approached (shown in Figure 1).
In a regional study (*Scherer et al., 2022*), this was validated against in-situ data at 815 reaches in Europe and North America with a median absolute error of 23 mm/km, almost complying with the SWOT science requirements of 17 mm/km.
IRIS covers 68.1% of the SWORD reaches classified as "*river*" or "*lake on river*".
Additionally, the IRIS dataset contains the minimum and maximum WSS, number of observations, and standard deviation per reach and approach. Using the SWORD "*reach_id*" as key, it can be used as a supplement to SWORD.
Figure 1a shows the mean number of observed days, the coverage with WSS results, and the mean temporal variation (maximum - minimum WSS) per 10% reach width percentiles for meandering and braided rivers using the classification by *Nyberg et al. (2022)*. The WSS extremes are useful for estimating river discharge uncertainties.
With increasing width, more observations can be provided. The mean temporal WSS variation is significantly larger for braided rivers than for meandering rivers, especially at widths below 171 m.

Summary and Conclusion

Using ICESat-2, we observe spatial and temporal WSS variations globally. The IRIS dataset can be used to research river dynamics, estimate river discharge, and correct water level time series from satellite altimetry. Additionally, by referencing SWORD as a common database, **IRIS can be combined and extended with SWOT observations.**
We intend to compare IRIS and SWOT observations to a common set of validation data once sufficient overlapping observations are available.

Data Availability

The "ICESat-2 River Surface Slope" (IRIS) dataset is available at Zenodo (https://doi.org/10.5281/zenodo.7516381) and will be updated continuously with the addition of new ICESat-2 data and upcoming releases of SWORD.

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