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High-resolution water surface slope of Polish rivers from two decades of multi-mission satellite altimetry measurements

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Water surface slope (WSS) of rivers is a key parameter in hydrological modelling, which allows for estimation of the transport and erosion capacity of a river, its flow velocity and discharge. On a local scale, WSS can be measured with a GNSS receiver installed on a boat, using remote sensing techniques (e.g. airborne lidar) or from a Digital Elevation Model (DEM). The most accurate method to measure WSS avoiding high-cost field campaigns is based on Water Surface Elevations (WSE) measured at in-situ stations. However, in poorly gauged rivers the neighboring gauges can be up to hundreds of kilometers apart, which inhibits a proper river profile observation. The gap in decreasing number of gauge readings is partially filled with satellite altimetry over rivers. Altimetry based WSE can be used to estimate WSS between neighboring measurements. Here, we present an innovative approach for estimating high-resolution WSS derived from multi-mission satellite altimetry for the largest Polish rivers.

In this study, we used measurements from 9 altimetry missions: CryoSat-2, Envisat, ICESat-2, Jason-2/-3, SARAL, Sentinel-3A/-B, and Sentinel-6A. These observations cover the years from 2002 to 2022. We extracted the river centerlines from the global “SWOT Mission River Database” (SWORD). In order to validate the obtained results, we used WSE from 81 gauges, which are maintained by the Institute of Meteorology and Water Management – National Research Institute (Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy, IMGW-PIB). These measurements are referenced to the Kronsztadt’86 vertical datum and they range from 01.2016 to 05.2022. Additionally, we used the reach-scale “ICESat-2 River Surface Slope” (IRIS) and the DEM-derived WSS values from SWORD.

To obtain WSS, we first determined WSE at each satellite pass crossing the studied river. Next, we split rivers into sections without dams and reservoirs. The Support Vector Regression (SVR) has been applied to reject outliers. Then, water levels were assigned to a given river kilometer (bin). For each of them a median WSE has been calculated. Finally, WSS were calculated at river sections between bins, excluding those disrupted by hydraulic structures. Finally, we weighted the section-wise WSS inversely proportional to the length of each section and applied a Least Square Adjustment with an additional Laplace condition to obtain bin-wise WSS for each river kilometer.

To assess the accuracy of the proposed approach, we compared the obtained WSS with the slopes between IMGW-PIB gauges. For large rivers (Vistula, Odra, Warta), the multi-mission approach revealed high accuracy with preliminary Root Mean Squared Error (RMSE) below 30 mm/km. For smaller, mountain rivers (San, Dunajec) the preliminary errors were slightly larger (RMSE ~100 mm/km). We also compared our accuracies with those of the slopes based on DEM models, lidar data, ICESat-2 altimetry, and SWORD database. In general, the multi-mission approach revealed the highest accuracy. The research is supported by the National Science Centre, Poland, through the project no. 2020/38/E/ST10/00295.