CryoSat-2 satellite radar altimetry for river analysis and modelling

The global coverage of in situ observations of surface water dynamics is insufficient to effectively manage water resources. Moreover, the availability of these data is decreasing, due to the lack of gauging stations and data sharing. Satellite radar altimetry, initially developed to monitor ocean water levels, also offers measurements of water levels of rivers and lakes on a global scale. Because of the continuous upstart of new missions, and sensor and processing innovations, the importance of satellite altimetry data for the hydrologic community is increasing.

CryoSat-2, launched by the European Space Agency (ESA) in 2010, is one of the more recent additions to the set of satellite altimeters. It is unique due to two characteristics. First, its radar altimetry instrument provides, besides conventional observations in Low Resolution mode (LRM), observations in Synthetic Aperture Radar (SAR) and Synthetic Aperture Radar Interferometric (SARIn) mode. SAR and SARIn have reduced footprint size in the along-track direction owing to delay/Doppler processing, potentially increasing observation accuracy. Second, CryoSat-2 is placed on a unique long-repeat orbit with a cycle of 369 days. This is different from previous and current satellite altimetry missions, which are in short-repeat orbits with cycles of 10 to 35 days.

The orbit configuration of CryoSat-2 is a challenge for hydrologic applications. Short-repeat missions allow deriving time series at locations where the satellite ground track repeatedly intersects with the river – the so-called virtual stations. Because of the long repeat cycle of CryoSat-2, its virtual station time series have a temporal resolution of 369 days, which is inadequate for most hydrologic applications. This requires rethinking some methods to process such data, distribute them to the hydrologic community and combine them with river models. However, the orbit configuration of CryoSat-2 also results in a small inter-track distance, providing measurements with unprecedented spatial resolution along rivers. These points were the main motivation for this PhD study.

Two case studies were chosen; the Po River in Italy, and the Brahmaputra River in South Asia. CryoSat-2 level 2 data, i.e. point observations of surface height, were filtered over high resolution river masks derived from Landsat imagery. This yielded roughly 340 observations per year over the Po River, and roughly 1300 per year over the Brahmaputra River. The CryoSat-2 observations were validated against in situ observations along the Po River. The average root mean square error (RMSE) between CryoSat-2 and in situ observations was found to be 0.38m, which is comparable to previous missions.

The CryoSat-2 water level observations then were used to parameterize 1-dimensional (1D) hydrodynamic river models. For the Po River, where surveyed cross sections are available, CryoSat-2 was used to calibrate channel roughness. The distributed CryoSat-2 data allowed calibrating channel roughness with a higher spatial resolution than possible in a conventional approach using in situ data. Over the ungauged Brahmaputra River, CryoSat-2 data were used to calibrate shapes of synthetic cross sections. For the calibrated model, the RMSE between simulated and CryoSat-2 observed water levels is 1.24m. It is assumed to accurately reproduce water level-discharge relationships; without relying on river cross section information.

Finally, the potential of CryoSat-2 data for updating hydrodynamic models was evaluated based on the Brahmaputra River case study. A flexible Data Assimilation (DA) framework was developed, which can assimilate observations of river state with any spatio-temporal resolution to a DHI MIKE HYDRO River 1D hydrodynamic model. DA can, amongst others, improve flood forecasting. Synthetic tests showed a high potential of CryoSat-2, improving discharge predictions of the model in terms of Continuous Ranked Probability Score (CRPS) by up to 32%, while real tests could improve the CRPS by up to 10%. Also, synthetic experiments were conducted to evaluate the impact of increased observation accuracy and different sampling patterns.

The results from this study highlight the value of CryoSat-2 altimetry data, which delivers water level observations with unprecedented spatial resolution along rivers. The study presented methods to cope with the distinct spatio-temporal distribution of the CryoSat-2 data and move beyond the common concept of virtual stations. Potentially, this flexibility opens up new opportunities for the use of remote sensing data in the hydrologic community.