Estimation of River Discharge using SWOT: full catchment coverage with optimal space and time resolution (ERDSWOT)

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1 Summary

Insufficient observational evidence of hydrological parameters and, more importantly, river discharge at the global scale is a major impediment for progress in hydrological modeling. As the data provision from in situ gauge networks is deteriorating, satellites come to the rescue. Although spaceborne sensors offer a synoptic and global view by their very nature, they do have their own limitations for a full catchment river discharge estimation. The SWOT mission aims to alleviate the limitations and significantly improve spaceborne estimates of river discharge. The SWOT mission will provide measurements of water surface elevation, river width and slope, through which discharge can be estimated for river widths down to 50–100 m. This project aims to greatly improve river discharge estimation, by innovative modeling of results from SWOT and existing satellite altimetry (water level) and satellite imagery (surface area). To this end, an Ensemble Kalman-Filter (EnKF) based method will be developed to best estimate river discharge at full-catchment scale (applicable to global scale), which can deal with non-stationarity due to man-made interference, natural behavior or climate change. Moreover, within the developed EnKF, an ensemble of SWOT discharge values from different existing discharge estimation algorithms are ingested into the observation equation, leading to an assimilated (combined) estimation of river discharge at full catchment scale.

2 Research questions

The following research questions are to be answered before the overarching goal of the project can be achieved

2.1 How to deal with non-stationarity of river discharge?

Several of the aforementioned methods rely on an implicit assumption of temporal stationarity of the time series involved. However, the statistics of discharge will change over time due to changes in channel geometry (sedimentation, erosion, etc.), to human interference (dams, levees, etc.) and to climate change. For such river basins any discharge estimation based on the assumption of stationarity could be biased due to an uncertain process model that relies on outdated data with outdated statistics. Addressing this research question is extremely important for developing both full-catchment densification and river discharge estimation methods. It leads to an array of associated questions. How to deal with inter-annual signals and trends in time series of water level, surface water storage and discharge? How to deal with regime change of hydraulic variables? How to address the effect of changes in channel geometry in the estimation of discharge and surface water storage? How to characterize statistically the non-stationary behavior in discharge and surface water storage due to climate change? How to best obtain the time lag between altimetric measurements along the river.

2.2 How to best combine multiple discharge estimation algorithms to obtain a multi-model ensemble?

Within the developed ensemble Kalman Filter, an ensemble of SWOT discharge values from different existing discharge estimation algorithms can be ingested into the observation equation. However, it is important to estimate a proper uncertainty for each method, so that the discharge values are best assimilated within the EnKF. Obtaining such a proper uncertainty for the estimated discharge is not trivial, since proper stochastic information should be available for all input parameters.

3 Approach

The research at the Institute of Geodesy (GIS) is inherently multidisciplinary and typically involves integration of theory, data analysis and modeling. Over the years GIS research has made contributions to the development of efficient methods and algorithms for the application of spaceborne sensors for hydrological purposes, especially by developing algorithms for river discharge estimation from spaceborne geodetic sensor data. Relevant to this proposal, for instance, is the work of Tourian et al. (2013), who developed a method to estimate discharge through *quantile function mapping*. The introduced method enables in principle to use the statistics of pre-altimetry discharge data for discharge prediction in the altimetry time-frame under a weak assumption of stationarity for discharge.

Sneeuw et al. (2014) assessed the skill of different *hydro-geodetic approaches* for estimating runoff. Their results show that a catchment-specific method that uses altimetry clearly outperforms the global (hydrological and hydro-meteorological) approaches. Further, Lorenz et al. (2014) have studied estimation of large-scale runoff from landmasses. That study constituted a vast global assessment of the closure of the hydrological and atmospheric water balances, combining a wide array of hydrological, geodetic and atmospheric datasets/models in all their permutations.

Tourian et al. (2016) developed a geodetic method that allows the use of multi-mission altimetry along a river. It connects all virtual stations of several satellite altimeters along a river hydraulically and statistically and produces water level time series at any location along the river, the so-called *densification method*. It operates by shifting the altimetry-derived hydrographs of all virtual stations according to a corresponding time lag. The time series are then normalized according to their statistical characteristics and, finally, stacked. The method was implemented over rivers with different morphologic and climate conditions including Po, Mississippi, Congo and Danube. Depending on which and how many altimeter missions are merged, the effective temporal resolution could be reduced to 3 days.

In a follow up work, Tourian et al. (2017) proposed a method which went beyond the conventional one-to-one relationship and the Bjerklie et al. (2005) equation. They estimated *daily river discharge* using a multitude of altimetric time series from different satellite altimetry missions over Niger River including its two major tributaries (Figure 1).

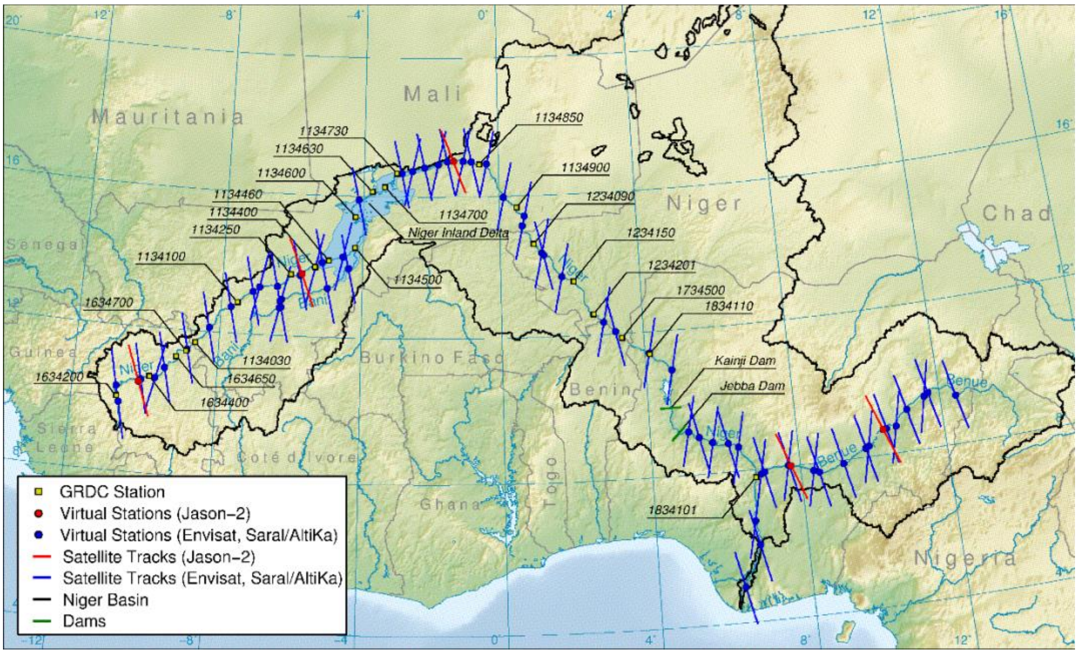

Figure 1: The Niger River, flowing through Guinea, Mali, Niger, Benin, Nigeria, and its two major tributaries Bani and Benue. Red lines and dots represent the groundtrack and the selected virtual stations from Jason-2, the blue lines and dots represent Envisat and SARAL/AltiKa

Within this project, we aim to develop an Ensemble Kalman Filter (EnKF) to benefit from the multiple discharge estimation algorithms. This allows us to cope with the limitations of different methods for capturing the whole discharge distribution, especially the known limitation of discharge algorithms in their upper tail of their distribution belonging to extreme events. Figure 2 shows the cumulative distribution function of in situ data and multiple discharge algorithms over the Po River at extreme values (Tourian et al, 2018).

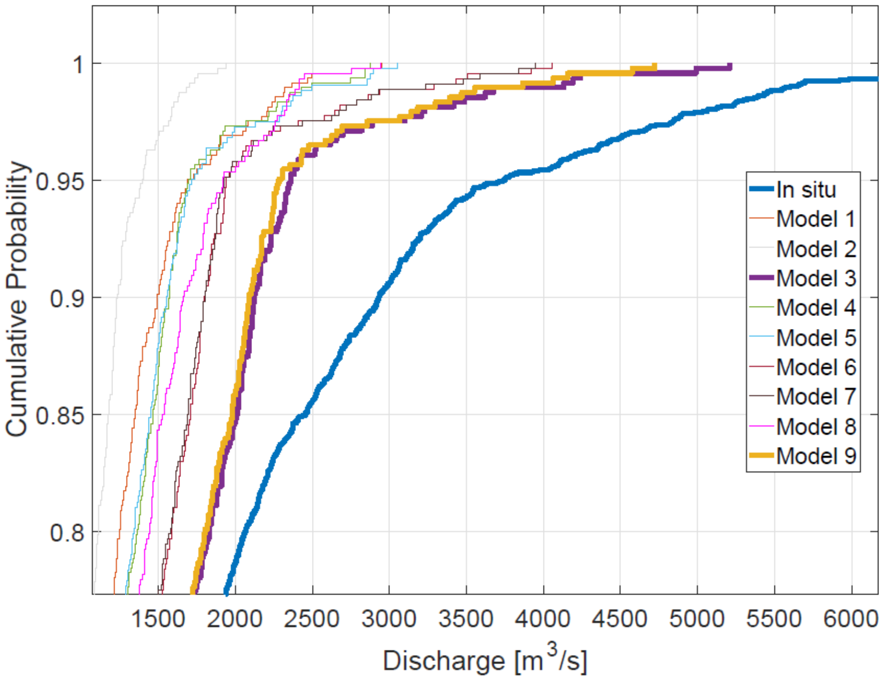

Figure 2: The cumulative distribution function (CDF) of the in situ data and the models for the river Po for the high peaks (2000 < Q < 6000)

4 Work plan

The work envisaged within the project is divided into 3 major work packages as follows

- **WP10:** Full-catchment river water level time series using SWOT, Jason- and Sentinel series

  This main work package is dedicated to improve the existing densification methodology, where on top of SWOT observations, we aim to use all available multi-mission altimetry together with channel width information over a river basin.

- **WP20:** Generation of an ensemble of discharge time series

  Several methodologies have been developed to estimate river discharge using SWOT-type observables including McFLI methods. With the help of conventional altimetry, SWOT and satellite imagery data several discharge algorithms are developed and validated for a possible use within the EnKF.

- **WP30**: EnKF based estimation of daily river discharge over entire river network

  Within this main work package, we aim to develop an EnKF algorithm to estimate river discharge over entire river basins. Special attention will be given to the develop a stochastic process model that can take the effect of dams and man-made structures into account

5 Anticipated results

- Spatially and temporally dense water level time series using SWOT and other altimetry missions over entire catchment
- Ensemble of river discharge time series along the river
- An Ensemble Kalman Filter (EnKF) for river discharge estimation at full-catchment scale which can deal with non-stationarity due to man-made interference, natural behavior or climate change
- Assimilated river discharge at full catchment scale, for which the hydraulic behavior of river system, water level measurements of SWOT and other altimetry mission, and the surface water extent from SWOT and other imagery satellites are best assimilated

6 Significance of investigation

This project is solicited in the fields indicated in the document provided by the ROSES call. It contributes to the "SWOT Algorithms and Data Products" by developing algorithms to estimate river discharge from SWOT data at full catchment scale applicable to global scale estimation of discharge. The project uses existing altimetry and imagery data including Jason-series and Sentinel satellites as complementary to SWOT observations to deliver an assimilated river discharge at full catchment scale. Moreover, in terms of methodological developments, this project will deal with significant scientific challenges leading to solutions, which facilitate the use of SWOT measurement for river discharge estimation and in general for studying the global earth system.

7 Bibliography

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