Title:
Towards a better understanding of the global hydrological cycle with SWOT

Subject:
Global Hydrologic Modeling

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Introduction and Objectives

The interest of the SWOT mission on the continental/global scale is to be able to observe all major watersheds and lakes, especially those still poorly observed *in situ*, making SWOT an excellent innovation for the study of the continental and global hydrological cycle. The mass exchanges at the surface water-atmosphere interface are today represented in a simplified way in most meteorological and climate models: generally no energy balance internal to the lakes and rivers, nor water balance in lakes/reservoirs. Artificial reservoirs are among the most common structural tools used in water management. They support various water uses, ranging from drinking water supply, irrigation, shipping to hydro-power and cooling. Knowing precisely the day-to-day water amount stored in a basin is often difficult due to the lack of data (lack of monitoring systems or difficulty to access data). In order to better understand and represent the complete hydrological cycle, i.e. the coupling between rivers and lakes/reservoirs and better take into account the anthropogenic effects on the water cycle, the prediction of the mass must be introduced in such models. Together, these actions will permit the development of a coherent and fully integrated representation of the global scale surface freshwater resources for the first time. This project will further refine methodologies (e.g.s Pedinotti et al., 2014; Emery et al., 2018, Bernus et al., 2020) which have been developed over the past decade in preparation of the mission for using SWOT data to improve the input parameters and the physics of the hydrological and hydrodynamic parameterizations in Earth System Models (ESMs). The objective is to be able to obtain global scale discharge and water storage changes for SWOT-observable rivers and lakes/reservoirs at the global scale after launch, especially for those which are poorly gauged. Thus SWOT provides an opportunity to make progress to better address the challenges of large-scale water resources in the face of climate change.

Approach

The two parallel actions in this proposal will mutually benefit from technical and methodological developments thereby contributing to the development of a consistent approach to optimally use SWOT measurements within the continental hydrological component of ESMs. The first centers around using SWOT measurements to obtain improved river storage and discharge estimates on the global scale using a hydrological models adapted for global climate models. The method determines optimal spatially distributed parameters which are difficult to measure or unknown, such as the Manning coefficient. It also considers sequentially correcting the model state when observations are available. The objectives of both are to provide improved discharge and river water storage estimates for forecasting as well as re-analysis over past periods.

The second theme focuses on improving lake storage and extent estimates within global climate models using SWOT measurements. Currently, lakes are generally represented in such models using one-dimensional approaches without considering the lake storage change: the main purpose of such schemes being to supply the atmosphere with reasonable estimates of heat and mass fluxes. But in order to fully couple all of the components of the continental hydrological cycle (rivers, lakes; groundwater, etc..), consideration of the lake and reservoir storage changes and exchanges with rivers are needed.

Rivers

A platform for the assimilation of SWOT virtual data as well as current nadir altimeter data has been set up in recent years within CTRIP (Fig.1). This work allowed us to make algorithmic choices in the context of data assimilation. Then, the work focused on the development of a data assimilation system (by Ensemble Kalman Filter, EnKF) allowing to either estimate model parameters or correct the model state (mainly river discharge). In the first phase of the project, i.e. pre-launch and before the availability of real SWOT observations, we propose to assess the whole processing chain from SWOT observations to analyzed river discharges via idealized assimilation experiments and to characterize the impacts of the different sources of error. In order to go beyond the traditional OSSEs, an independent model will serve as a reference to simulate SWOT observations (either water level or river discharge) using the SWOT large scale simulator (CNES). These systems have been applied over different large basins and have reached a high degree of maturity, but none of them has been tested and evaluated at the global scale, yet. By the end of the project, we propose to set up an assimilation system able to ingest SWOT products – and potentially observations from other altimetry missions – into hydrological models that simulate river discharges at the global scale and at a spatial resolution compatible with SWOT products. SWOT product may be either water level or derived discharge over around 10 km reaches. To increase the robustness of the methodology, multiple assimilation systems will be studied and compared, relying on different routing models; CTRIP, RAPID (in collaboration with NASA-JPL) and CaMa-Flood (in collaboration with the University of Tokyo) and assimilation strategies (Kalman algorithm, state or forcing update). We will also explore the added value of assimilating SWOT-derived discharge product instead of a water level product. Finally, these assimilation methodologies will be extended to the global scale.

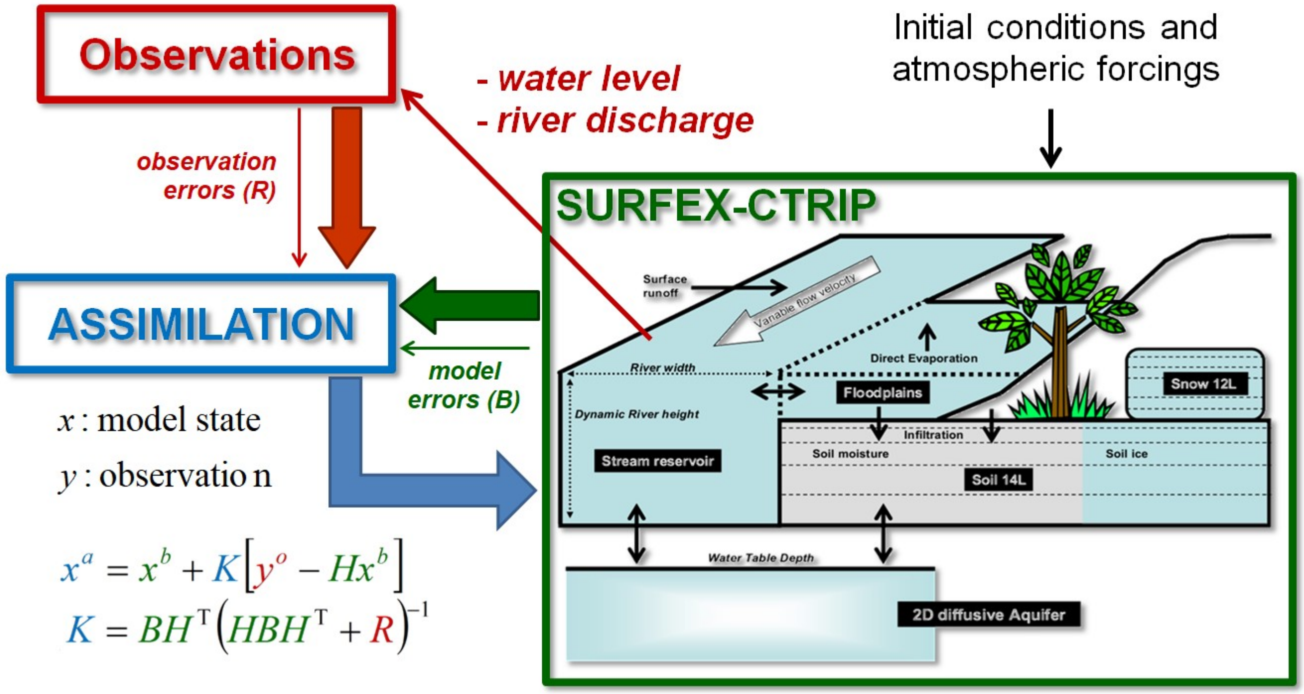

Fig.1 A schematic of one of the models, CTRIP, used within this project and the assimilation method.

Lakes and Reservoirs

Currently, lake mass models are being developed coupled to both surface energy balance models for a lake and land surface models (which simulate the surface runoff which is used as a lateral mass flux into the lakes). In addition, new representations of anthropization (notably dams/reservoirs) will also be introduced and used. This configuration allows the simulation of the dynamic height of the lakes and the explicit exchanges with the hydrographic network, along with dynamic changes in the extent of lakes. An example of the hydrological network and coupling with the Great Lakes is shown in Fig.2. When the water budget parameterizations have been developed in our models, we will perform sensitivity experiments to assess the processes and parameters that present the largest sensitivity to depth and compare the respective potential contribution of SWOT lake products on the model performances. Next, we plan to proceed towards an assimilation of SWOT data into lake and reservoir models, using methodologies similar to those developed for rivers (which already have a certain maturity). We will design our data assimilation experiments together and compare the results obtained at different scales from the local to the regional scale. These developments will make it possible to calculate variations in volume and water surface, to better take into account anthropogenic effects on the water cycle such as the amount of water available for irrigation and domestic use. This step will also define the best strategies for future satellite data, such as SWOT. These new developments, applicable in climate models, will help quantify future potential changes in water resources in response to climate change.

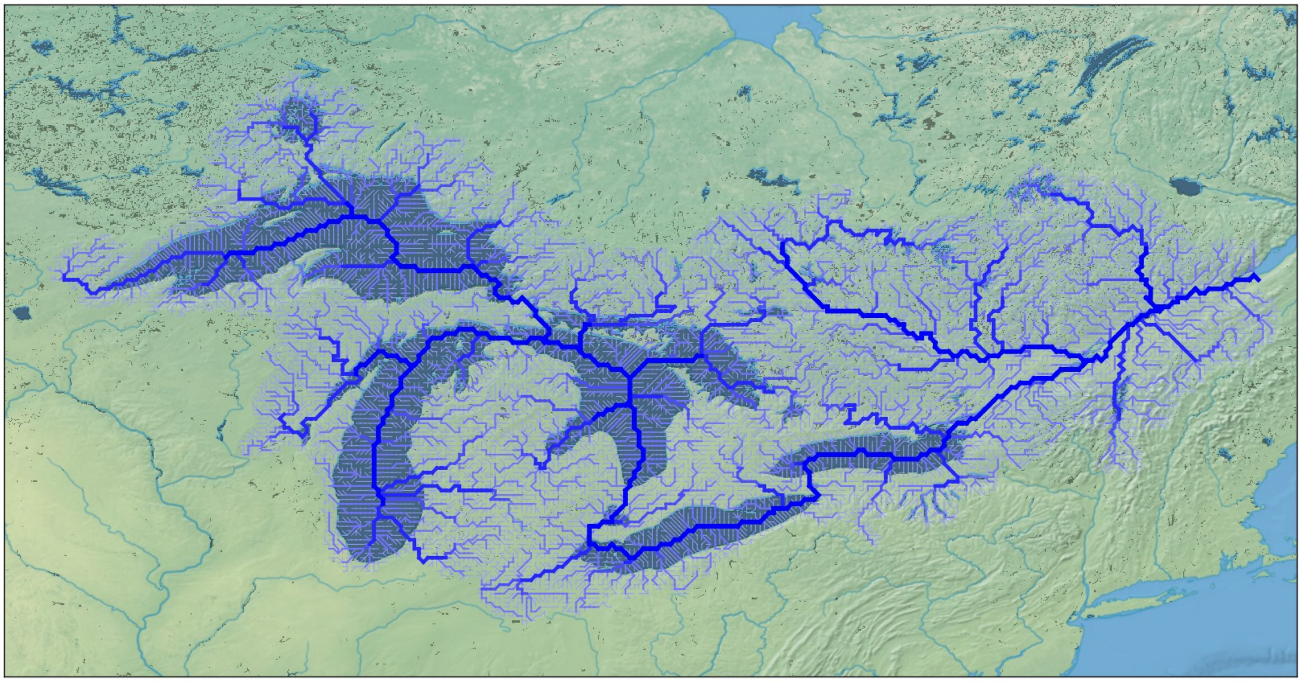

Fig.2. The representation of the Great Lakes within the CTRIP model platform.

Expected Results

We anticipate making significant improvements and advances in the area of integration of SWOT measurements into large scale hydrological and lake models. Indeed, coarse resolution models have specific issues related to scale and to the simplified representation of hydrological and hydro dynamical processes. Therefore, we are building upon experience gained during previous TOSCA projects and developing more elaborate and robust data assimilation techniques along with optimal use of the simulator (along with other independent synthetic estimates of SWOT measurements through multiple collaborations within TOSCA and ROSES), which are increasingly more adapted towards using SWOT measurements in large scale models. ii) The previous item will lead to improved discharge estimates, which then overlap with several other TOSCA and ROSES proposals concerning the development of discharge algorithms. iii) In terms of lake processes, we are working on adapting a commonly used lake model (used in operational numerical weather prediction) into models with a dynamic reservoir which will be more amenable for the use of SWOT measurements in terms of constraining the lake surface area and optimally incorporating height changes to both improve the lake mass and to estimate other fluxes, such as inflow. Over the longer term of the project, this will also permit the coupling of rivers and lakes (via an exchange of mass and via dams/anthropogenic controls). The newly modified models will then be available to the climate and numerical weather prediction communities, which could help propagate the use of SWOT data in the hydro-meteorological (climate and operational weather and hydrological prediction) community. iv) Finally, owing to the global scale approach, we will provide a characterization of surface waters in terms of both rivers and lakes/reservoirs as a global scale hydrological reanalysis, in addition to being able to quantify their interactions with other components of the continental hydrological cycle using an integrated modeling approach (ground water, runoff, irrigation...).

Milestone

One of the main anticipated milestones of this project is to obtain an improved representation of the global water cycle in Earth System Models, especially those participating in the Climate Model Intercomparison Project (CMIP) experiments, which is one of the main elements of the Intergovernmental Panel on Climate Change (IPCC) reports. The improved representation of lakes/reservoirs, rivers, their coupling and their links to ground water, vadose zone soil moisture and irrigation will form a comprehensive picture of the continental hydrological cycle thereby opening the door to improved estimates of water resources in both seasonal prediction and climate change scenario work. Assimilation of water surface measurements from remote sensing sensors in basin scale hydrological models is an emerging topic which has seen significant advances in recent years, in part, due to SWOT mission preparations. The data assimilation techniques should be applicable (both within and beyond the SWOT mission) to many of the other large scale hydrological, river routing and lake/reservoir models which have been developed in recent years. SWOT measurements represent a significant leap forward in terms of quantifying the temporal variations of lake surface and their mass variations, and it will enable us to observe and monitor significantly more lakes than was previously possible. In addition, the assimilation methodology for rivers and lakes can be used in conjunction with existing assimilation methods in synergy with other remotely-sensed surface observations, thus we will be getting an increasing amount of observational data into multiple components of the continental hydrological cycle. This project seeks to develop such methodologies, which we hope will be useful for the overall scientific community.

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