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Downscaling coarse grid hydrodynamic model simulations over large domains

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SUMMARY

It is evident in recent literature that hydrodynamic modelling efforts have moved to increasing spatial coverage while trying to preserve simulation accuracies at computationally efficient coarse grids (100 m to several km). However, it is clear that there is a need to retain fine spatial resolutions at large scales wherever possible in order to still retrieve meaningful information from models or indeed observations, such as identifying individual assets at risk from flooding for instance. Since it is currently rather impractical to model hydrodynamics across areas larger than a couple of thousand km^2 at a fine spatial resolution (finer than 100 m), this paper proposes a method to downscale coarse model simulations (model grid size of 100 m to several km) to a fine spatial resolution. The method is mass conservative and uses a hydraulic 1D approach within the channel and a pseudo region-growing algorithm on the floodplain. Comparison to a high resolution reference model over a domain size much larger than those traditionally modelled showed that downscaling a 600 m grid resolution hydrodynamic LISFLOOD-FP model to 30 m leads to average accuracies greater than 30 cm in water depth and above 90% in inundation area for a high accuracy digital elevation model (DEM). When employing a SRTM DEM accuracies were still between 0.5 m and 1.5 m for water depth but agreements in inundated area were much lower than 90%. We speculate that for simulating the world's major rivers and their floodplains at a resolution of 90 m, even a speed-efficient model could take over three years to simulate inundation patterns at that resolution for a one-year hydrograph. However, it is expected that the proposed downscaling method could be used to downscale LISFLOOD-FP model simulations run at a 3 km resolution with reasonably similar accuracies and at only a fraction of the computational time required by the 90 m model.

1. Introduction

The importance of water moving through rivers and associated floodplains for sustaining life and ecosystems and the risks it can pose to both are all well known, yet there is very limited knowledge about the quantity, timing and storage flux of water that is entering and exiting rivers and floodplains on a regional to global scale (e.g. Alsdorf et al., 2007).

Quantification of such hydrodynamic variables could be achieved either through long term data collection from dense network measurement stations world-wide either from the ground, air or space, or through global scale simulations from a hydrodynamic model. Currently both approaches undoubtedly suffer from many obvious limitations. On the one hand, ground based gauging stations provide accurate data but coverage is declining and they require very costly maintenance over the long term and are sparsely located on a global scale thus contributing only moderately to the task. Remotely sensed information obtained from airborne and orbital platforms, on the other hand, can overcome the limited spatial coverage but still suffers (to some extent at least) from revisit times too long to allow tracking of high frequency hydrodynamics.

In areas where observations are not available or to complement existing observations, large scale 2D hydrodynamic models can be employed with model domain sizes ranging from many thousand to millions of km^2 to simulate the variables necessary to understand hydrodynamics and associated change globally. With the recent development of 2D hydrodynamic models with higher order physics but still efficient computational speed (Bates et al., 2010; Yamazaki et al., 2011; Neal et al., 2012) and advances in relevant computing technologies such as code parallelization, higher precision chips and efficient memory and energy usage, the possibility of modelling at the right temporal (hourly time steps) and spatial resolution (<1 km, preferably <100 m) over large areas may slowly become feasible.

Despite these notable developments, a large scale model run at the desired spatial resolution (<100 m) could take up to three years

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to compute a one-year hydrograph over only the world's major rivers and their inland delta floodplains (see Syvitski et al. (2009) for more details on these areas), ignoring all the medium to small size catchments covering areas smaller than 100,000 km^2. These large hydro-systems exhibited a total flooded area since 2001 of around 246,440 km^2 (Syvitski et al., 2009) and a model resolution of 90 m $\times$ 90 m over such an area (actual model domain size could easily be 20 times larger than the area covered by wet cells, i.e. at least 5 million km^2) would be achievable with the aforementioned compute time (tested on a 5 $\times$ 3.47 GHz Quad-Core Intel Xeon with 24 GB of memory) which, according to Syvitski et al. (2012), is high enough to resolve necessary floodplain geomorphologic and topographic detail, except in urban areas of course. As three years or even only one third of that time (which may be achievable through MPI, GPU or domain decomposition implementation) is obviously impractical, a 2D hydrodynamic model with a novel sub-grid scale channel treatment as recently proposed by Neal et al. (2012) could be run at 3 km $\times$ 3 km with a reasonable compute time of only 0.6 of a day for the same area, at the expense however of the resolvable floodplain detail. In their study on the Niger River basin, Neal et al. (2012) demonstrate that their sub-grid module generates the same level of in-channel accuracies and stability as a full 2D inertial base model (see Bates et al. (2010)) they used and thus could be a viable option. The simulated floodplain dynamics could subsequently be downscaled to the desired 90 m $\times$ 90 m resolution since SRTM elevation data are available at this spatial resolution for most of the world's floodplains with reasonable accuracies, better than 2 m RMSE in the vertical in some floodplains (Schumann et al., 2008). Important to note is although 90 m resolution may be possible in some cases, most areas around the world would require averaging grids over distances of several hundreds of meters to attenuate the noise content in the SRTM data.

Using a test reach in the U.S. (Fig. 1) this paper demonstrates how a sub-grid scale coarse resolution model can be downscaled to a very fine resolution with near identical performance in water level, volume and flooded area to a high resolution reference model. A downscaling approach is proposed and tests are repeated for a SRTM digital elevation model (DEM).

2. Test site, available data and models

2.1. Test site and available data

The test site is a reach of the Scioto River in the lower Scioto basin of about 100 km in length, downstream of Columbus, OH in the Eastern United States (Fig. 1) covering a model domain area of 2150 km^2. The Scioto River is a major tributary of the Ohio River with a total length of 371 km. It has a total drainage area of 16,900 km^2 and an average discharge of about 190 m^3 s^{-1} and flows primarily through agricultural land (Lyons et al., 2006). In the lower Scioto River valley the floodplain is wide (often 2–3 km) compared to the bankfull width of the river. The Scioto River is prone to flooding especially in late winter or early spring when the river has received substantial amounts of rain and melted

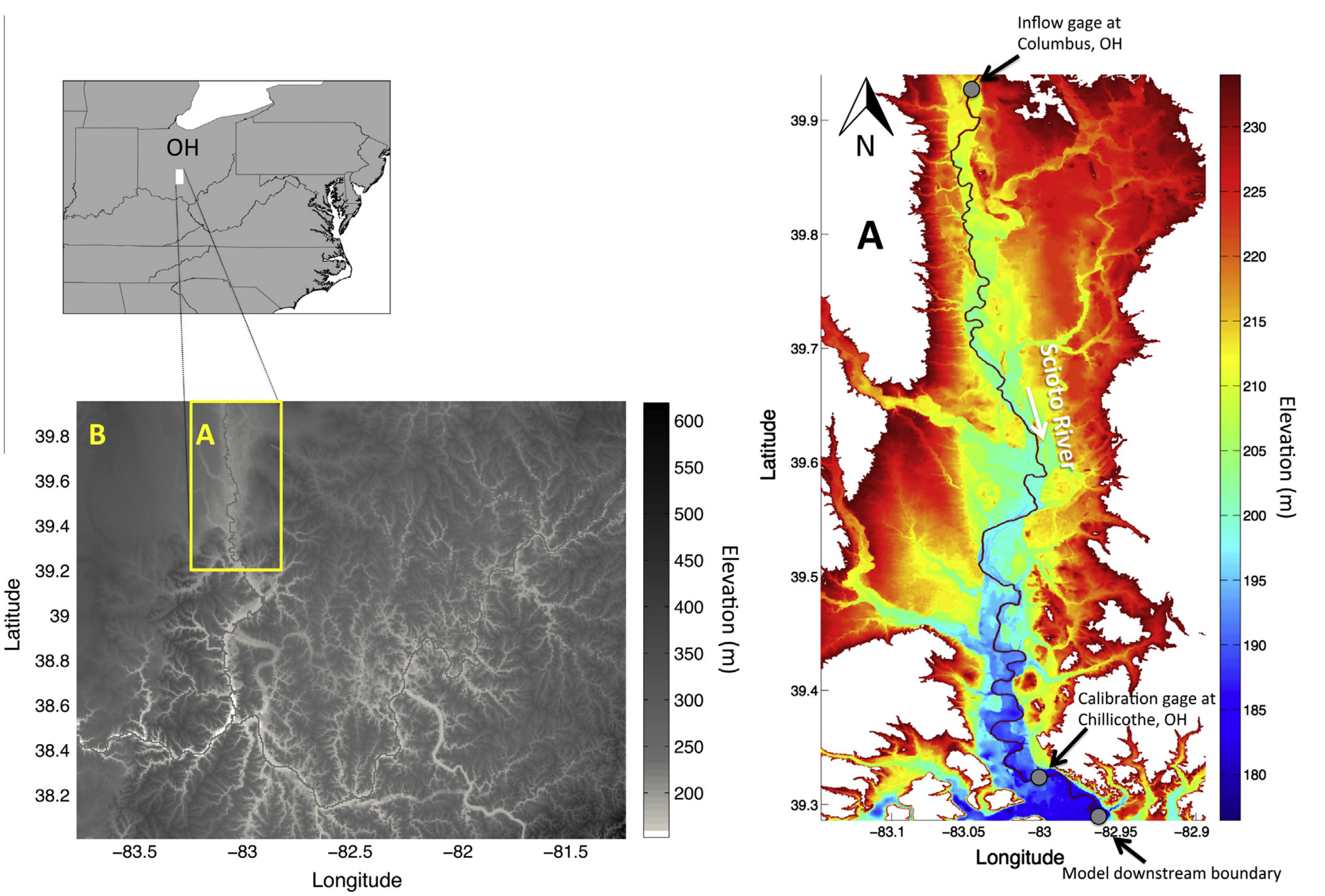

Fig. 1. Scioto River test reach location. Map showing the Eastern U.S. (top left), the 40,000 km^2 model domain of the Ohio River basin (NED DEM aggregated to 600 m $\times$ 600 m pixels) and the Scioto River downstream of Columbus, OH, with the USGS gauges (NED DEM at 30 m resolution) (right). An approximate inundatable area can be depicted by the blue to yellow shading; the stream centerline is also plotted. The area shown in A is the model domain for the Scioto River test reach and area B is the Ohio River model domain referred to in Section 5. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)