A combination of high resolution hydro-sedimentary data and distributed numerical modelling to understand internal catchment erosion processes

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Context and objectives

Soil erosion and suspended sediment (SS) transport understanding is an important issue in terms of soil and water resources management [1]. Erosion by water is considered as the main threat to soils in Europe generating irreversible soil loss which is especially problematic for agricultural productivity [2]. Excessive sediment yields from hillslopes to river channels can contribute to reservoir siltation, degradation of aquatic habitats and to the export of nutrients or contaminants to downstream water bodies. Erosion is especially important in the Mediterranean, mountainous context where the highest rates of sediment yield are reported [3].

Given the importance and recurrence of the negative effects caused by soil erosion, decision makers are increasing their demands for distributed numerical models able to simulate SS fluxes within catchments to assess mitigation strategies in a context of climate and land use changes. However, it is clear that at present the performance of these models remains poor and far below the expectations of decision makers [4]. This may be due to the fact that these models focus only on what occurs at the outlet without ensuring accurate simulation of the SS production and transfer within catchments [5]. Another limitation has been the lack of high resolution datasets that are used to improve the representation of internal catchment processes and better constrain distributed models. Recently, the installation of instrument networks and the publication of comprehensive, high-resolution data sets (e.g. ref. [6]) as well as the possibility to identify the spatial origin of SS at a high resolution with low-cost fingerprinting techniques (e.g. ref [7]) open up new possibilities to better understand catchment processes and to better evaluate physical based, distributed hydro-sedimentary models.

The activation (or lack thereof) of sediment sources is often explained with (dis-) connectivity of the sources to the river network. However, this term remains ambiguous and difficult to quantify [8] as it depends both on structural connectivity, i.e. “the extent to which landscape units (at multiple spatial scales) are contiguous or physically linked” [8] and on functional connectivity which also includes process intensities, interactions and feedbacks.

Study sites, data set and model

The study presented here uses two comprehensive data sets recorded at two meso-scale catchments that include high-resolution data on discharge, distributed precipitation, SS concentration and the quantified contributions of sediment sources to SS samples taken during > 80 flood events in the two streams since 2007. The latter was obtained with a SS fingerprinting protocol based on spectrocolorimetry [7]. The study sites are located in the Mediterranean region: The Claduègne catchment (43 km^2), located in the Ardèche, is part of the OHMCV observatory and the Galabre catchment (20 km^2), located in the Alpes de Hautes Provence, belongs to the Draix-Bléone observatory. Both catchments are found on contrasting geologies and have extensive badlands, constituting the main sediment sources.

Iber [9] is a hydrodynamic model that was initially developed to solve the complete 2D Saint-Venant equations including rainfall and infiltration on the hillslopes [10]. It was recently coupled to a soil erosion model including rainfall and runoff detachment. The use of this model in rainfall-runoff applications has been validated at the plot scale [10, 11] and it is now applied for the first time on a meso-scale catchment for hydro-sedimentary application. The model can be obtained free of charge [12] but the official version does not include the soil erosion module yet.

Distributed Hydro-sedimentary Modelling

The overall objective is to benefit from the combined use of distributed modeling with high resolution hydro-sedimentary data to improve our understanding of the role played by rainfall variability on sediment connectivity. To achieve this goal two issues are addressed:

1) Parameterization: Hydro-sedimentary models with a high number of parameters often face the problem of equifinality, when the model is calibrated solely with fluxes measured at the outlet. Here, the available sediment fingerprinting data offers the possibility to verify parameter choices with both the information available on sediment source contributions and the amount of rainfall on each sediment source. A sensitivity analysis is conducted to assess the impact of the parameterization of the erosion module on model output in terms of SS flux. The model is highly sensitive to the sources rainfall erodibility coefficient α_r [kg m^{-3}]. Measurements of this parameter are available mostly at very small scales (< 1 m^2 – few dozens of m^2). In physically based models these values make sense at the plot scale where the size of the mesh is comparable to the scale at which they were obtained. However, in meso-scale catchment models where the size of the modelling units is in the order of several 100 m^2 this parameter has to be replaced by an effective parameter. This can be obtained using measured SS yield at the outlet integrated over longer time spans (years) and neglecting deposition processes of sediments once they are eroded. A parameterization of the model in this manner leads to SS export from the catchment in the same order of magnitude of the measured one.

2) Connectivity: The distributed hydro-sedimentary model offers the opportunity to directly quantify the contribution of more or less connected sediment sources to the sediment flux at the outlet. The structural connectivity of the erosion zones is quantified with the GIS-based indicators for structural connectivity introduced by Borselli and co-authors [13]. Then the erosion zones are classified based on this indicator and their contribution to the suspended sediment flux at the outlet is systematically assessed. The model geometry in the two models set up in Iber consists of three basic units: erosion zones, hillslopes that are not active erosion zones and the river network. Connectivity of the erosion zones depends crucially on the definition of the hydrographic network in the model. Thus, a sensitivity analysis is performed to assess to which extent the choice of the threshold of contributing area to define a river reach has an impact on the functional connectivity predicted by the numerical model

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