A critical zone observatory dedicated to suspended sediment transport: the meso-scale Galabre catchment (southern French Alps)

Legout C.[1], Freche G.[1], Biron R.[2], Esteves M.[2], Navratil O.[3], Nord G.[1], Uber M.[1], Grangeon T.[4], Hachgenei N.[1], Boudevillain B.[1], Voiron C.[2], Spadini L[1].

[1]Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, 38000 Grenoble, France

[2]Univ. Grenoble Alpes, IRD, CNRS, Grenoble INP, IGE, 38000 Grenoble, France

[3]Univ. Lumière Lyon 2, Laboratoire Environnement Ville Société, 69500 Bron, France

[4]Bur Rech Geol & Minieres BRGM, Orleans, France

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Summary Paragraph

The 20 km² Galabre catchment belongs to the French network of critical zone observatories. It is representative of the sedimentary geology and meteorological forcing found in Mediterranean and mountainous areas. Due to the presence of highly erodible and sloping badlands of various lithologies, the site was instrumented in 2007 to understand the dynamics of suspended sediments (SS) in such areas. Two meteorological stations including measurements of air temperature, wind speed and direction, air moisture, rainfall intensity, raindrop size and velocity distribution are installed both in the upper and lower part of the catchment. At the catchment outlet, a gauging station records the water level, temperature and the turbidity (10 min. time-step). Water and sediment samples are collected automatically to estimate SS concentration-turbidity relationships, providing SS fluxes quantifications with known uncertainties. The

sediment samples are further characterized by measuring their particle size distributions (PSD) and by applying a low-cost sediment fingerprinting approach using spectrocolorimetric tracers. Thus, the contributions of badlands on different lithologies to total SS flux are quantified at a high temporal resolution providing the opportunity to better analyze the links between meteorological forcing variability and watershed hydrosedimentary response. The set of measurements was extended to the dissolved phase in 2017. Both the river electrical conductivity and its major ion concentrations are measured each week and every three hours during storm events. This allows progress in understanding both the origin of the water during the events and the partitioning between particulate and dissolved fluxes in the critical zone.

Site Descriptions and Measurements

The 20 km² Galabre catchment belongs to the Draix-Bléone Observatory (https://oredraixbleone.inrae.fr/en/) which is also part of the research infrastructure OZCAR (Gaillardet et al., 2018). It is located in the southern French pre-Alps (Figure 1a) in the Bléone catchment (Figure 1b). The Bléone river is a tributary of the Durance river which delivers 18% of the total sediment fluxes released by the Rhône river to the Mediterranean Sea (Sadaoui et al., 2016). The elevations of the Galabre catchment range from 735 to 1909 m a.s.l. (above sea level) with mean slopes of 54%, 19% and 6% for hillslopes, intermittent rivers and the main river, respectively. The geology is composed of sedimentary rocks overlain by shallow soils (depth < 50 cm). The different geology types include limestones (34 %), marls (30 %), gypsum (9 %), molasses (9%) and quaternary deposits (18%) (Esteves et al., 2019). Unvegetated badlands covering 9% of the total area are distributed throughout the catchment on all types of geologies (Figure 1c). Grasslands cover 40% of the total area while forests cover more than half of the catchment (34% deciduous and 17% coniferous). The climate is both mountainous and Mediterranean, characterized by freezing periods in winter and both high temperatures and high rainfall intensities in summer.

Meteorology

Two meteorological stations are installed at la Robine sur Galabre (since 2014) and at Ainac (since 2019) with similar sensors and configurations (Table 1). From 2008 to 2019 Ainac was equipped with an autonomous tipping bucket raingauge (Rainew 111). The common set of measurements at both stations are air temperature and moisture (Campbell Sc. CS215 sensors), wind speed and direction measured with a 2D ultrasonic anemometer (WindSonic4), precipitation measured with a tipping bucket raingauge (Precis Mecanique 3039) and drop size distributions (DSD) measured with an optical disdrometer (OTT Parsivel2). All sensors are supplied by a combination of battery and photovoltaic panel and controlled by a data logger (Campbell CR800) triggering measurement cycles every 15 min. (1 min. for DSD). Data are transmitted each day to a remote ftp server by a 2G/3G modem (Sierra Fastrack FXT009) through the LoggerNet software (Campbell Sc.).

Hydrology

The hydrological station was installed at la Robine sur Galabre in 2007 under a bridge. The river Galabre flows on limestone slabs at this location ensuring a high stability of the cross section without sedimentation or bed scouring. The configuration of this station is similar to that of the meteorological stations (i.e. data logger, energy supply and remote data transfer) with measurements performed every 10 minutes. Water temperature is measured with a Decagon ES-2 sensor. Water level is measured with a 24-GHz radar (Paratronic Cruzoe). Thirty-five discharge measurements were performed, either using a current flow meter or dilution methods to build a stage-discharge rating curve. As these manual measurements ranged from 0.017 $m^3 s^{-1}$ to 0.948 $m^3 s^{-1}$, an extrapolation was performed for higher water levels with a 1-D hydraulic model (HEC-RAS software; Esteves et al., 2019).

Particulate matter

The hydrological station also includes a turbidimeter (WTW Visolid 700-IQ) connected to a transmitter (IQ182) performing low concentration measurements by 90° diffusion and high concentrations by backscattering. When turbidity thresholds of 5 and 20 g L^{-1} SiO_2 are exceeded, the data logger triggers sample collection by an automatic sequential water sampler (Teledyne ISCO 3700) every 3 and 1 hour, respectively. The 500 ml water and sediment samples are processed in the laboratory to measure the suspended sediment concentration (SSC), particle size distribution (PSD) and spectral reflectance. Most SSC measurements are obtained by weighing the sample after drying for 24 h at 105°C. When SSC are visually assessed to be small (< 2 g L^{-1}) measurements are performed by filtration through pre-weighed 0,45µm fibreglass filters and then weighed after drying. Continuous time series of SSC are obtained with turbidity-SSC relations either general (whole period) or specific to a given flood event. Navratil et al. (2011) assessed the uncertainties at the storm event scale to be, on average 20% and 30% for SSC and suspended sediment yield (SSY), respectively. PSD were measured on samples collected during five events using a laser diffraction sizer (Malvern Mastersizer 2000). The protocol detailed in Grangeon et al. (2012) provides, for each measured sample, eleven PSD measurements, the first one being the effective PSD, while the others provide the disaggregation dynamics of suspended particles and an absolute PSD. An aggregation degree was deduced from these measurements. The dried sediment samples were also measured with a portable spectrocolorimeter (Konica Minolta 2600d). Similar measurements were also carried out on source soil samples collected in badland areas of different geological nature. From the diffuse reflectance spectra, a low-cost sediment fingerprinting approach was developed (Legout et al., 2013). It allows to quantify with a maximum uncertainty of 20% the contribution of primary geological sources molasse, marl and limestone to each SS sample.

Dissolved matter

Data characterizing the dissolved phase are available since 2017. Measurements are performed in samples collected automatically by the sequential sampler at a weekly frequency and a time step of a few hours during runoff events. Electrical conductivity is measured with a portable sensor (WTW 340i) regularly calibrated with commercial standards. Major ion concentrations (F^-, Cl^-, NO_2^-, Br^-, NO_3^-, SO_4^{2-}, Na^+, NH_4^+, K^+, Ca^{2+}, Mg^{2+}) are measured by ionic chromatography (Metrohm modular systems 732-733).

Results and interest of the data set

The Galabre catchment is characterised by high SSC with 50% of the total SSY transported at SSC exceeding 13g L^{-1}. It is highly intermittent with 50% of the total SSY transported in less than 0.1% of time and with less than 5% of the water volume. SS transport occurs mainly during two periods associated to two distinct rainfall regimes (Esteves et al., 2019). In early winter (November and December) widespread rainfall events associated to low rainfall intensities and large durations (>5 h) lead to a high hydrological connectivity within the catchment generating high liquid discharges (e.g. max. 34 $m^3 s^{-1}$ on 24/12/09). Even though the SSC are usually low during these events (max. 16 g L^{-1} on 24/12/09), SS fluxes remain high. In summer (June to September), convective storms are usually brief (1-2 h) over limited areas (few square km) leading to high SSC (e.g. max. 360 g L^{-1} on 9/9/12) with low flow discharge (max. 0.3 $m^3 s^{-1}$ on 9/9/12) due to a low hydrological connectivity. While the median effective diameters of SS are small (10µm), they are aggregated at various levels and exhibit either a stability or variability at the event scale (Grangeon et al., 2012). The sediment fingerprinting also revealed a stability of the geological source contribution for some events while others exhibit high temporal variations (Legout et al., 2013).

The overall data set allows to address process-based understanding of the transfer of water and matter in the critical zone, particularly the links between sediment export from meso-scale watershed and meteorological forcing. It was already used in studies on sediment budgets at larger scales in the Bléone catchment in order to assess the spatial variations of erosion intensity (Evrard et al., 2011) or the drivers of the temporal variability of SS fluxes (Navratil et al., 2012). It also allows to test conceptual or physically based models investigating assumptions such as the respective contribution of badlands and the riverbed to SSY (Park et al., 2019, Misset et al., 2019) or the role of the catchment configuration on SS connectivity (Uber et al., 2020).

Data availability

The data set summarised in Table 1 can be accessed through the OSUG data center at https://doi.osug.fr/public/DRAIXBLEONE_GAL/index.html. A brief description and the data policy is provided for the overall data set (https://doi.org/10.17178/DRAIXBLEONE_GAL.all) and for each sub data set. Alternatively, some data sets can be visualized directly on the BDOH database (https://bdoh.irstea.fr/DRAIX/nos-donnees?site=Galabre). BDOH also enables the interpolation of time steps for export in multiple formats after creating an account.

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