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

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

3

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10

11 **Keywords**

12 Hydrology, meteorology, soil erosion, sediment transport, sediment fingerprinting,  
13 hydrochemistry, critical zone, observatory.

14 **Summary Paragraph**

15 The 20 km<sup>2</sup> Galabre catchment belongs to the French network of critical zone observatories. It  
16 is representative of the sedimentary geology and meteorological forcing found in Mediterranean  
17 and mountainous areas. Due to the presence of highly erodible and sloping badlands of various  
18 lithologies, the site was instrumented in 2007 to understand the dynamics of suspended  
19 sediments (SS) in such areas. Two meteorological stations including measurements of air  
20 temperature, wind speed and direction, air moisture, rainfall intensity, raindrop size and velocity  
21 distribution are installed both in the upper and lower part of the catchment. At the catchment  
22 outlet, a gauging station records the water level, temperature and the turbidity (10 min. time-  
23 step). Water and sediment samples are collected automatically to estimate SS concentration-  
24 turbidity relationships, providing SS fluxes quantifications with known uncertainties. The

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

#### 34 **Site Descriptions and Measurements**

35 The 20 km<sup>2</sup> Galabre catchment belongs to the Draix-Bléone Observatory  
36 (<https://oredraixbleone.inrae.fr/en/>) which is also part of the research infrastructure OZCAR  
37 (Gaillardet et al., 2018). It is located in the southern French pre-Alps (Figure 1a) in the Bléone  
38 catchment (Figure 1b). The Bléone river is a tributary of the Durance river which delivers 18%  
39 of the total sediment fluxes released by the Rhône river to the Mediterranean Sea (Sadaoui et  
40 al., 2016). The elevations of the Galabre catchment range from 735 to 1909 m a.s.l. (above sea  
41 level) with mean slopes of 54%, 19% and 6% for hillslopes, intermittent rivers and the main  
42 river, respectively. The geology is composed of sedimentary rocks overlain by shallow soils  
43 (depth < 50 cm). The different geology types include limestones (34 %), marls (30 %), gypsum  
44 (9 %), molasses (9%) and quaternary deposits (18%) (Esteves et al., 2019). Unvegetated  
45 badlands covering 9% of the total area are distributed throughout the catchment on all types of  
46 geologies (Figure 1c). Grasslands cover 40% of the total area while forests cover more than  
47 half of the catchment (34% deciduous and 17% coniferous). The climate is both mountainous

48 and Mediterranean, characterized by freezing periods in winter and both high temperatures and  
49 high rainfall intensities in summer.

50

### 51 *Meteorology*

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

63

### 64 *Hydrology*

65 The hydrological station was installed at la Robine sur Galabre in 2007 under a bridge. The  
66 river Galabre flows on limestone slabs at this location ensuring a high stability of the cross  
67 section without sedimentation or bed scouring. The configuration of this station is similar to  
68 that of the meteorological stations (i.e. data logger, energy supply and remote data transfer)  
69 with measurements performed every 10 minutes. Water temperature is measured with a  
70 Decagon ES-2 sensor. Water level is measured with a 24-GHz radar (Paratronic Cruzoe).  
71 Thirty-five discharge measurements were performed, either using a current flow meter or  
72 dilution methods to build a stage-discharge rating curve. As these manual measurements ranged

73 from  $0.017 \text{ m}^3 \text{ s}^{-1}$  to  $0.948 \text{ m}^3 \text{ s}^{-1}$ , an extrapolation was performed for higher water levels with  
74 a 1-D hydraulic model (HEC-RAS software; Esteves et al., 2019).

75

### 76 *Particulate matter*

77 The hydrological station also includes a turbidimeter (WTW Visolid 700-IQ) connected to a  
78 transmitter (IQ182) performing low concentration measurements by  $90^\circ$  diffusion and high  
79 concentrations by backscattering. When turbidity thresholds of 5 and  $20 \text{ g L}^{-1} \text{ SiO}_2$  are  
80 exceeded, the data logger triggers sample collection by an automatic sequential water sampler  
81 (Teledyne ISCO 3700) every 3 and 1 hour, respectively. The 500 ml water and sediment  
82 samples are processed in the laboratory to measure the suspended sediment concentration  
83 (SSC), particle size distribution (PSD) and spectral reflectance. Most SSC measurements are  
84 obtained by weighing the sample after drying for 24 h at  $105^\circ\text{C}$ . When SSC are visually  
85 assessed to be small ( $< 2 \text{ g L}^{-1}$ ) measurements are performed by filtration through pre-weighed  
86  $0,45\mu\text{m}$  fibreglass filters and then weighed after drying. Continuous time series of SSC are  
87 obtained with turbidity-SSC relations either general (whole period) or specific to a given flood  
88 event. Navratil et al. (2011) assessed the uncertainties at the storm event scale to be, on average  
89 20% and 30% for SSC and suspended sediment yield (SSY), respectively. PSD were measured  
90 on samples collected during five events using a laser diffraction sizer (Malvern Mastersizer  
91 2000). The protocol detailed in Grangeon et al. (2012) provides, for each measured sample,  
92 eleven PSD measurements, the first one being the effective PSD, while the others provide the  
93 disaggregation dynamics of suspended particles and an absolute PSD. An aggregation degree  
94 was deduced from these measurements. The dried sediment samples were also measured with  
95 a portable spectrophotometer (Konica Minolta 2600d). Similar measurements were also carried  
96 out on source soil samples collected in badland areas of different geological nature. From the  
97 diffuse reflectance spectra, a low-cost sediment fingerprinting approach was developed (Legout

98 et al., 2013). It allows to quantify with a maximum uncertainty of 20% the contribution of  
99 primary geological sources molasse, marl and limestone to each SS sample.

100

#### 101 *Dissolved matter*

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

#### 108 **Results and interest of the data set**

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

122 a stability of the geological source contribution for some events while others exhibit high  
123 temporal variations (Legout et al., 2013).

124 The overall data set allows to address process-based understanding of the transfer of water and  
125 matter in the critical zone, particularly the links between sediment export from meso-scale  
126 watershed and meteorological forcing. It was already used in studies on sediment budgets at  
127 larger scales in the Bléone catchment in order to assess the spatial variations of erosion intensity  
128 (Evrard et al., 2011) or the drivers of the temporal variability of SS fluxes (Navratil et al., 2012).  
129 It also allows to test conceptual or physically based models investigating assumptions such as  
130 the respective contribution of badlands and the riverbed to SSY (Park et al., 2019, Missot et al.,  
131 2019) or the role of the catchment configuration on SS connectivity (Uber et al., 2020).

### 132 **Data availability**

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

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