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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 km² 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 km² 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° 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°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 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 ($>5\text{ h}$) 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 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 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. A brief description and the data
135 policy is provided for the overall data set (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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145 **References**

- 146 Esteves M., Legout C., Navratil O., Evrard O. 2019. Medium term high frequency observation of
147 discharges and suspended sediment in a Mediterranean mountainous catchment. *Journal of Hydrology*
148 568: 562-574.
- 149 Evrard O., Navratil O., Ayrault S., Ahmadi M., Némery J., Legout C., Lefèvre I., Poirel A., Bonté P., Esteves
150 M. 2011. Combining suspended sediment monitoring and fingerprinting to determine the spatial origin
151 of fine sediment in a mountainous river catchment. *Earth Surface Processes and Landforms* 36(8):
152 1072-1089.
- 153 Gaillardet, J., Braud, I., Hankard, F., and co-authors: OZCAR: the French network of Critical Zone
154 Observatories. *Vadose journal*, 17(1), 2018, doi: 10.2136/vzj2018.04.0067
- 155 Grangeon T., Legout C., Esteves M., Gratiot N., Navratil O. 2012. Variability of suspended particles size
156 during highly concentrated flood events in a small mountainous catchment. *Journal of Soils and*
157 *Sediments* 12(10): 1549-1558.
- 158 Legout C., Poulenard J., Némery J., Navratil O., Grangeon T., Evrard O., Esteves M. 2013. Quantifying
159 suspended sediment sources during floods in headwater catchments by spectrophotometry. *Journal of*
160 *Soils and Sediments* 8: 1478-1492.
- 161 Misset C., Recking A., Legout C., Poirel A., Cazihlac M., Esteves M., Bertrand M. 2019. An attempt to
162 link suspended load hysteresis patterns and sediment sources configuration in alpine catchments.
163 *Journal of Hydrology* 576: 72-84.
- 164 Navratil O., Esteves M., Legout C., Gratiot N., Némery J., Willmore S., Grangeon T. 2011. Global
165 uncertainty analysis of suspended sediment monitoring using turbidimeter in a small mountainous
166 river catchment. *Journal of Hydrology* 398: 246-259.
- 167 Navratil O., Evrard O., Esteves M., Legout C., Ayrault S., Némery J., Mate-Marin A., Ahmadi M., Lefèvre
168 I., Poirel A., Bonté P. 2012. Temporal variability of suspended sediment sources in an alpine catchment

169 combining river/rainfall monitoring and sediment fingerprinting. *Earth Surface Processes and*
170 *Landforms* 37(8): 828-846.

171 Park J., Batalla R.J., Birgand F., Esteves M., Gentile F., Harrington J.R., Navratil O., Lopez-Tarazon J.A.,
172 Vericat D. 2019. Influences of catchment and river channel characteristics on the magnitude and
173 dynamics of storage and re-suspension of fine sediments in river beds. *Water* 11 (5): 878.

174 Sadaoui M., Ludwig W., Bourrin F., Raimbault P. 2016. Controls, budgets and variability of riverine
175 sediment fluxes to the Gulf of Lions (NW Mediterranean Sea). *Journal of Hydrology* 540 : 1002:1015.

176 Uber M., Nord G. Legout C., Cea L. How do modeling choices impact the representation of structural
177 connectivity and the dynamics of suspended sediment fluxes in distributed soil erosion models? *Earth*
178 *Surface Dynamics Discussion*, <https://doi.org/10.5194/esurf-2020-64>, in review, 2020.

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