Spatial and temporal dynamics of suspended sediment fluxes in an alpine river: the Arc and Isère rivers, France

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November 21, 2022

Abstract

Fine sediment dynamics is an important issue in alpine rivers since it impacts both dam management (decrease of the reservoir capacity, flushing strategy) and river management (interaction between fine sediment and vegetation, gravel bar stabilisation, flood risk). Suspended Particle Matter (SPM) is generally assumed to be transported as washload although significant exchanges with the river bed have been detected in several cases. As a consequence but also due to the variable SPM sources and differences in the discharge and sediment wave velocities, one can often observe a hysteresis behaviour during hydrological events that evolves spatially along the system. In this study, we will present results from a network of hydro-sedimentary stations (measuring both water discharge and sediment concentration) along a reach of 120 km starting from the Arvan River at its confluence and the Arc and Isère rivers, that is part of the ZABR (or Rhône Basin Long Term Environmental Research Observatory). The SPM dynamics is analysed for different types of events (large flood, spring flood, flushing event, debris flow). In particular, we focus on the potential of erosion or deposition between each station by calculating the total SPM flux during each event at each station as well as the hysteresis behaviour using a hysteresis index. The evolution of these parameters is related to input parameters such as discharge and sources and grain size characteristics of the suspension. Indeed, most observed sediment exchanges (erosion or deposition) occur on the gravel bars when inundated, and depend on settling characteristics of the SPM. Also the experimental site provides some useful data for estimating advection and dispersion characteristics of various SPM events that could be used to validate numerical models.

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AGU 100 FALL MEETING Washington, D.C. | 10–14 Dec 2018

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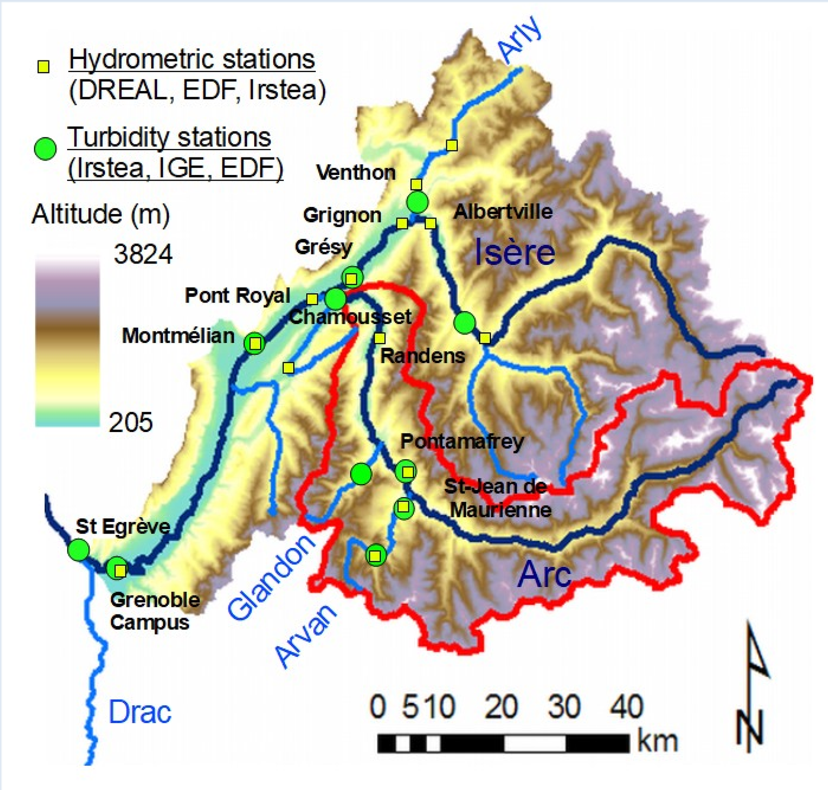
Arc-Isère monitoring observatory

- Arc and Isère watersheds characterized by high Suspended Particulate Matter (SPM) concentrations (black marls) in very anthropogenized valleys
- Main contribution to the Rhône River (with Arve, Saône and Durance rivers)
- Network of hydro-sedimentary stations in nested catchments (Arvan, Arc, Isère)
- Part of the ZABR (Rhône basin observatory) since 2007

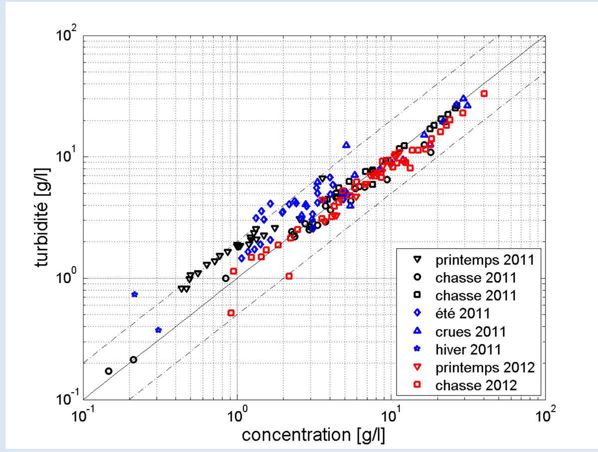
Hydro-sedimentary stations	Stakeholder	Starting period
Arvan amont	Dreal/Irstea	2010-
Arvan aval	Irstea	2009-
Arc Pontamafrey	EdF/Irstea	2007-
Arc Chamousset	SPC/Irstea	2011-
Isère Montmélian	EdF	2010-
Isère Grenoble	IGE/ENSE³	2006-
Isère Tullins	EdF	2002-
Isère Beaumont	CNR/EdF	2009-

Main hydro-sedimentary stations of the Arc-Isère rivers

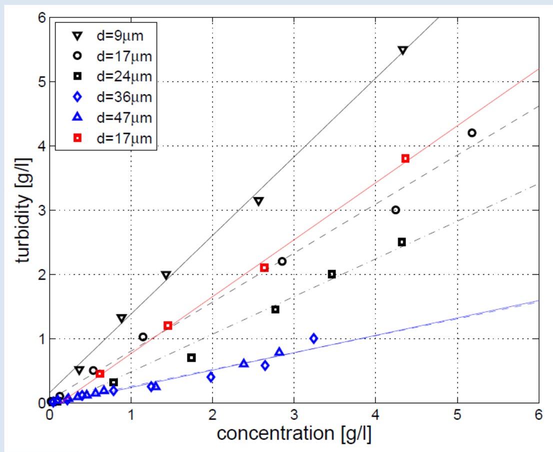


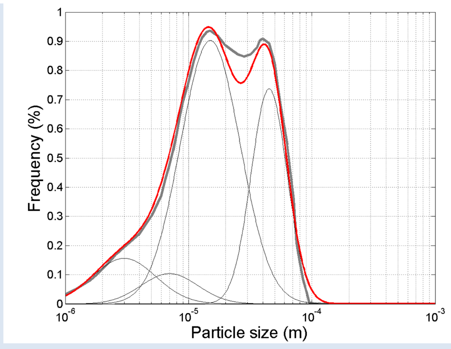
Turbidity-concentration relashionships

- Turbidity: a surrogate of the SPM concentration
- Not normalized for *T*>4000 NTU (approx 4g/l)
  → Need of a rating curve $C_{SSM}=\alpha_T T$
- But turbidity is sensitive to color, shape, and above all size of particules (Thollet et al., 2013) $C_{SSM}=\alpha_{dT}\, d\, T$
- Grain Size Distribution (GSD) of SPM generally poorly sorted (clay, fine silt and coarse silt, Camenen et al., 2016) and variable in time (and space)
- Two main strategies for the sediment rating curve
  - a unique rating curve for estimating yearly averaged fluxes
  - specific rating curves for each event depending on the GSD in particular to distinguish events such as debris flows, spring floods, flushing events, and large summer/autumn floods



Turbidity-concentration relationship for the Pontamafrey station





Turbidity-concentration relationship as a function of grain size for Arc river sediments and typical SSM GSD

Annual fluxes

All discharge and SPM concentration data available on the BDOH data base (adaptive timestep, $\Delta t \approx 5$ min) :

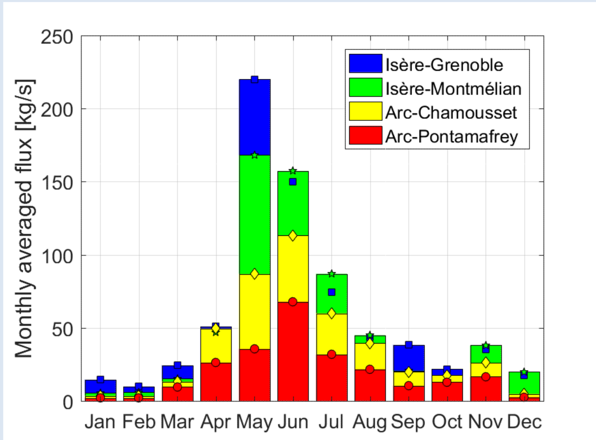
https://bdoh.irstea.fr/ARC-ISERE/

Instantaneous sediment flux : $\Phi_{SSM}(t)=C_{SSM}(t)\times Q(t)$

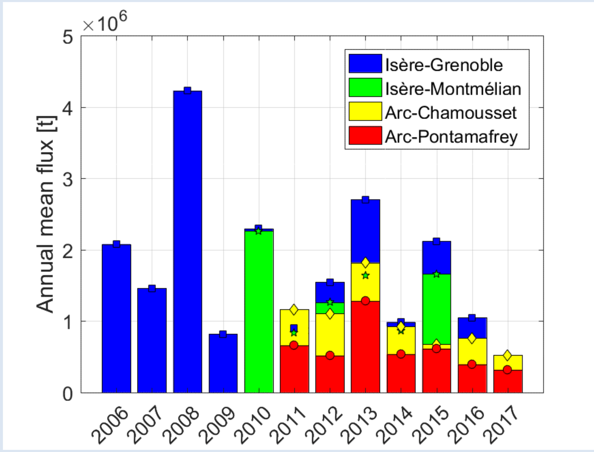
Estimation of total fluxes over specific periods $T=t_i-t_{i-1}$:

$$M_T=\int_T \Phi_{SSM}(t)\,dt$$

- High variability in yearly averaged fluxes. At Isère-campus (Grenoble) station, *M* varies from 0.8 to 4.3 million tons per year since 2006 (Mano et al., 2009 ; Némery et al., 2013).
- The Arc River yields between 30 % and nearly 100 % of the total fluxes at Grenoble
- Inputs from the upstream Isère catchment mainly due to punctual floods whereas inputs from Arc catchment due to both floods and spring period (snow melt)
- Arc dam flushing events represent between 2 % and 10 % of the yearly flux instead of ≈50 % for large spring floods (May 2008, June 2013).



Monthly mean fluxes



Annual mean fluxes

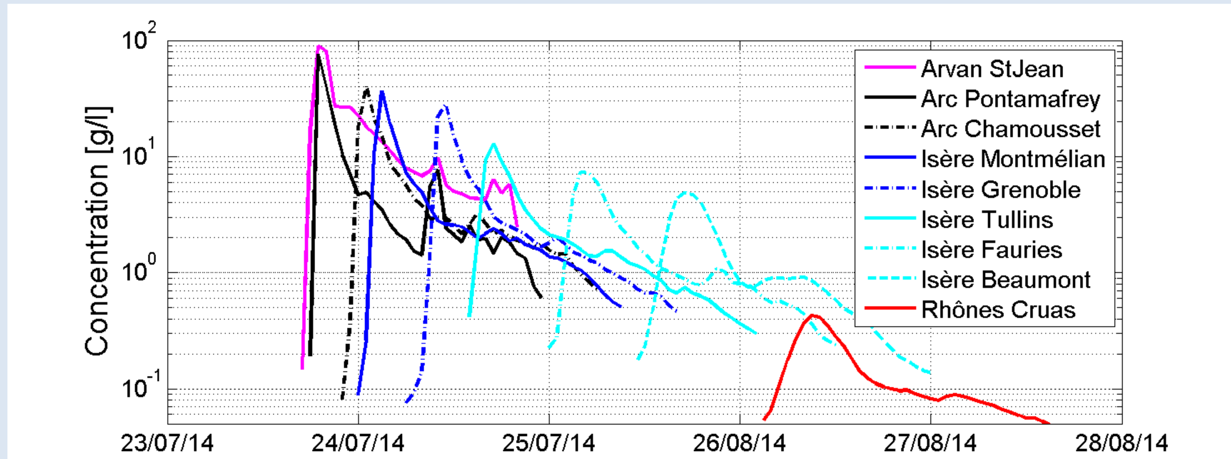
Year	Mass (kt)	Events	Mass (kt)	% year
2011	653	Flush June 11	16.5	2.5
2012	509	Flush June 12	4.8.9	9.6
2013	1280	Flood June 13	540	42.3
2014	533	Flush June 14	13.8	2.6
2015	607	Flush June 15	17.1	2.8
2016	392	Flush June 16	68.4	17.5
2017	319	Flush June 17	24.9	7.8

Yearly and event fluxes estimated at Pontamafrey (Arc)

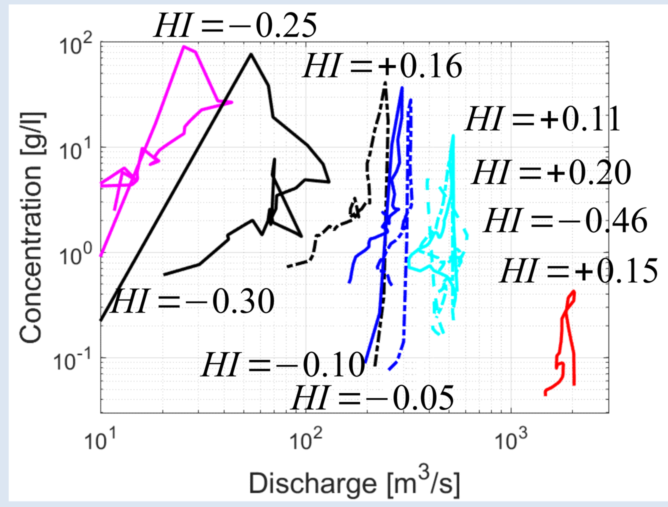
Spatio-temporal analysis of events

Possible spatial and temporal study of events (flood, flush, debris flow) based on the hydrosedimentary station network.
→ Characterisation of the event dynamics including tributary inputs and fine sediment budget on reached between two stations (erosion or deposition, Antoine et al., 2013) ; impact of vegetation.
→ Evaluation of fine sediment exchanges over gravel bars, characteristics of deposits (Legout et al., 2018).

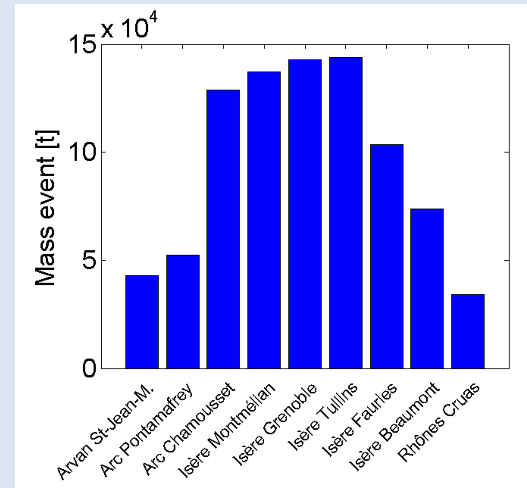
- Floods (Arc River) : Low exchange with the bed, possible deposition in the Isère River
- Flushing event : Dilution at the restitution and confluence, deposition at the confluence, erosion in the Isère River
- Debris flows : Nearly no exchange with the bed



Time series of concentrations measured at different hydrosedimentary stations along Arvan, Arc, Isère and Rhône rivers for a debris flow event Ravoire in July 2014)



Concentration-discharge hysteresis for each station



Total flux over the debris flow event for each station

Estimation of an hysteresis index following Lloyd et al. (2016) and Misset et al. (2018) :

$$HI=\text{mean}\left[C^*_{i,rising}(Q^*_i)-C^*_{i,rising}(Q^*_i)\right] \qquad C^*_i=\frac{C-C_{min}}{C_{max}-C_{min}} \qquad Q^*_i=\frac{Q-Q_{min}}{Q_{max}-Q_{min}}$$

HI > 0 (clockwise) : station is close to the source ; *HI* < 0 (counterclockwise) : station is far from the source.
Not very efficient to characterise debris flows (discharge not necessarily related to concentration).

Conclusions and perspectives

- Arc-Isère observatory : ideal observatory for studying fine sediment transfers in an anthopogenized alpine river system.
- High temporal and spatial density of data
  → Accurate estimation of fine sediment budget over events and of yearly averaged budgets
  → Possibility to analysis specific event dynamics
- Significant variability of the events in the system (spring flood, summer/autumn flood, flushing event, debris flow) to be better characterise (total fluxes, sediment budget, *HI*, etc.)
  - Estimation of advective and diffusive terms (Camenen et al, 2008) ; Application of a 1D model (Guertault et al., 2016)
  - Important to link fine sediment dynamics observed through the observatory and exchange with the bed (erosion or deposition) depending on hydrologic (*Q*, *C*) and morphologic conditions (gravel bar characteristics, vegetation cover, etc.)

ANR project DEAR (Deposit and Erosion of fine sediments in Alpine Rivers, 2019-2022) : ***https://dear.irstea.fr***

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