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

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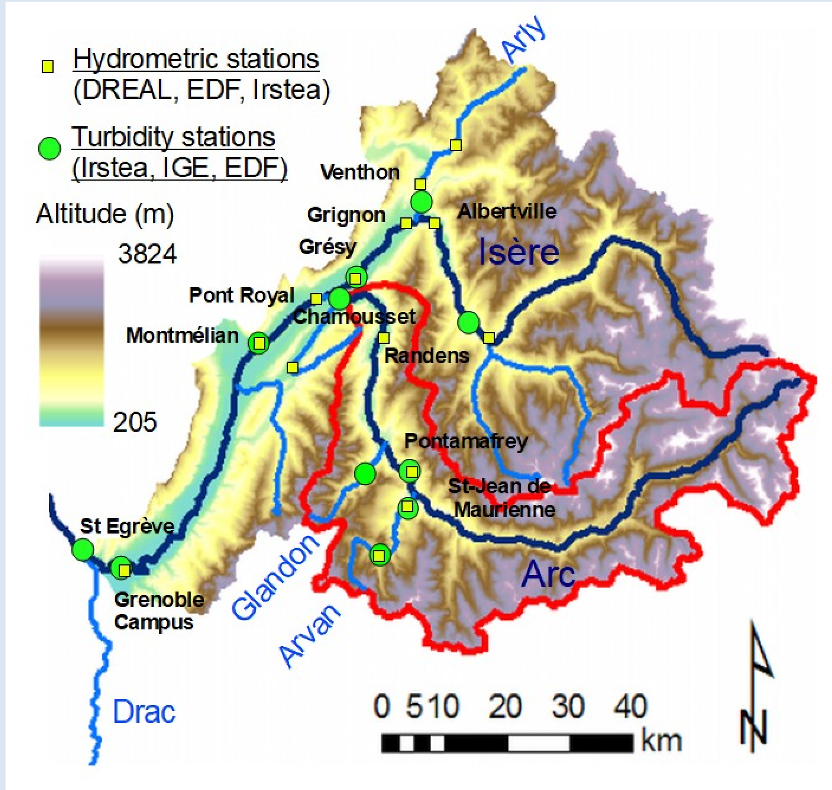
Camenen, B.[1*], Archambaud, J.[1], Thollet, F.[1], Rousseau, C.[2] & Némery, J.[2]

1 : Irstea Lyon UR RiverLy, 5 rue de la Doua - BP 32108 69616 Villeurbanne Cedex
2 : Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP*, IGE, 38000 Grenoble (* Institute of Engineering)
* contact : benoit.camenen@irstea.fr

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

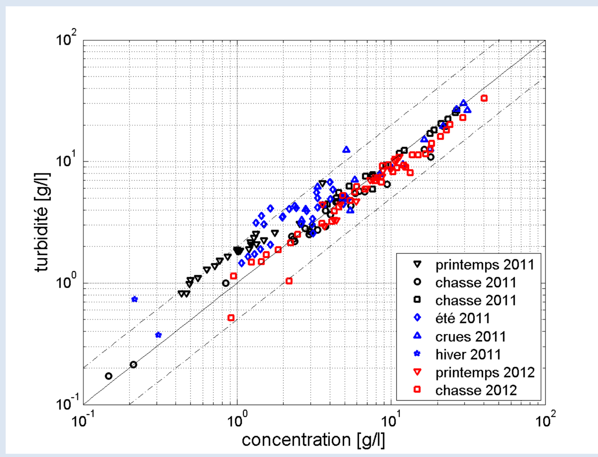
Hydro-sedimentary stations	Stakeholder	Starting period
Arvan amont	Dreal/Irstea	2010-
Arvan aval	Irstea	2009-
Arc Pontamafrey	EdF/Irstea	2007-
Arc Chamousset	SPC/Irstea	2011-
Isère Montmélian	EdF	2010-
Isère Grenoble	IGE/ENSE³	2006-
Isère Tullins	EdF	2002-
Isère Beaumont	CNR/EdF	2009-



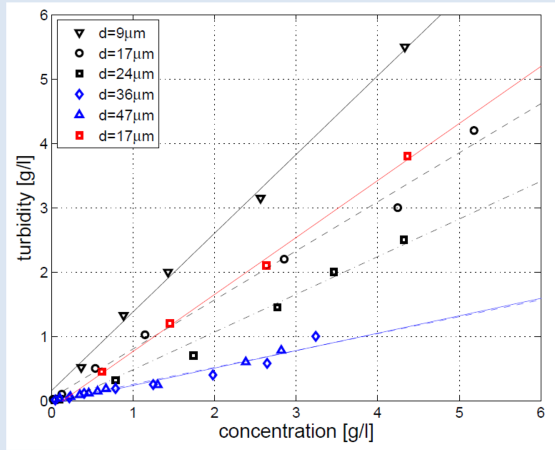
Main hydro-sedimentary stations of the Arc-Isère rivers

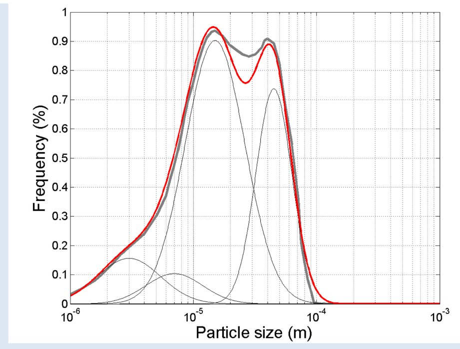
Turbidity-concentration relashionships

- 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) :

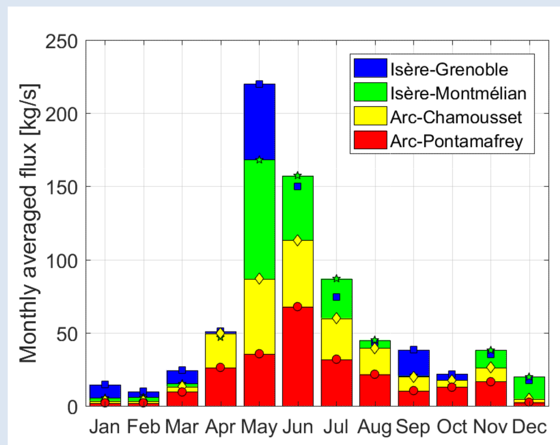
https://bdoh.irstea.fr/ARC-ISERE/

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

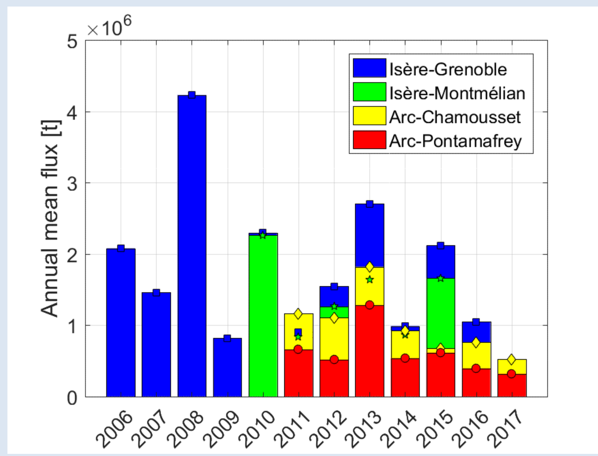
Estimation of total fluxes over specific periods $T = t_i - t_{i-1}$:

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

- 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

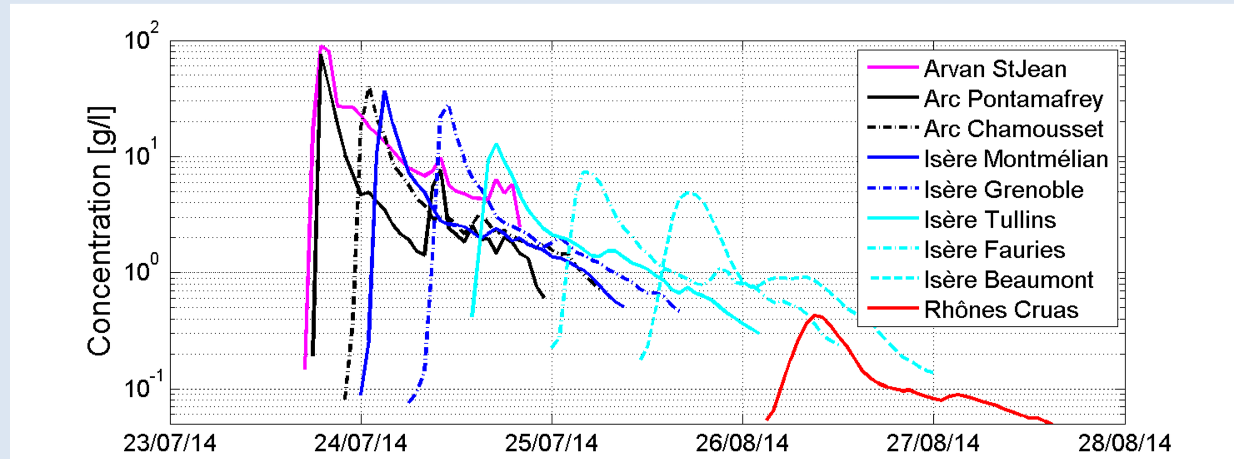
Year	Mass (kt)	Events	Mass (kt)	% year
2011	653	Flush June 11	16.5	2.5
2012	509	Flush June 12	4.8.9	9.6
2013	1280	Flood June 13	540	42.3
2014	533	Flush June 14	13.8	2.6
2015	607	Flush June 15	17.1	2.8
2016	392	Flush June 16	68.4	17.5
2017	319	Flush June 17	24.9	7.8

Yearly and event fluxes estimated at Pontamafrey (Arc)

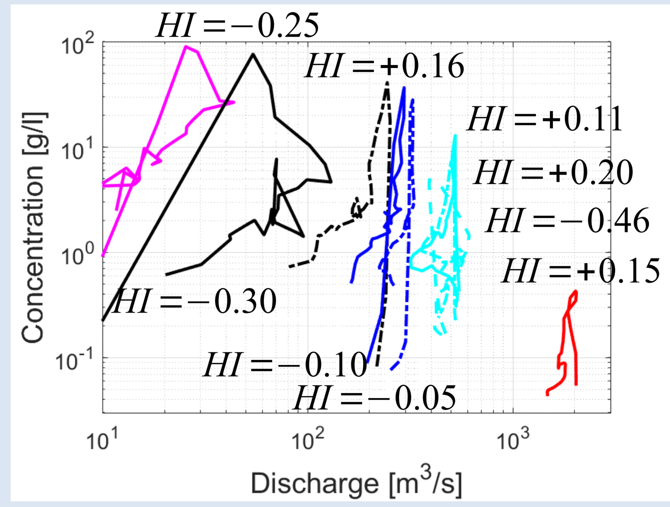
Spatio-temporal analysis of events

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).

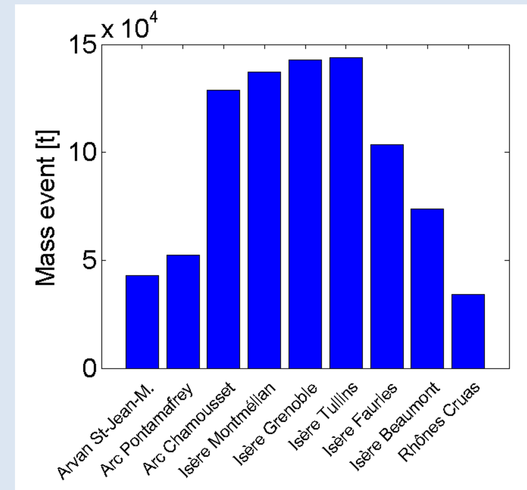
- Floods (Arc River) : Low exchange with the bed, possible deposition in the Isère River
- Flushing event : Dilution at the restitution and confluence, deposition at the confluence, erosion in the Isère River
- Debris flows : Nearly no exchange with the bed



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) :

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

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***

References :

Antoine G., Jodeau M., Camenen B., Esteves M., Nemery J. & Lauters F. (2013).Estimation des flux de matières en suspension lors des chasses hydrauliques de l'Arc de 2006 à 2011. La Houille Blanche, 4:43-49 (in French).
Camenen, B., Jodeau, M. & Le Coz, J. (2008). Conceptual modelling of the sediment flux during a flushing event (Arc en Maurienne, France). Proc. 8th Int. Conf. on HydroScience and Eng., Nagoya, Japan. 8p.
Camenen, B., Perret, E., Herrero, A., Berni, C., Thollet, F., Buffet, A., Dramais, G., Le Bescond C., & Lagouy M. (2016). Estimation of the volume of a fine sediment deposit over a gravel bar during a flushing event. Proc. River Flow conference, St Louis, Missouri, USA, July 2016, CDRom, pp. 533-540.
Guertault, L., Camenen B., Peteuil, C., Paquier, A. & Faure, J.-B. (2016). One-dimensional modelling of suspended sediment dynamics in dam reservoirs. J. Hydraulic Eng., 142(10.1061):1-9.
Legout, C., Droppo, I., Coutaz, J., Bel, C. & Jodeau, M. (2018). Assessment of erosion and settling properties of fine sediments stored in cobble bed rivers: the Arc and Isère alpine rivers before and after reservoir flushing. Earth Surface Processes & Landforms, 43(6) : 1295-1309.
Lloyd C.E.M., Freer, J.E., Johnes, P.J.& Collins, A.L. (2016). Technical Note: Testing an improved index for analysing storm discharge–concentration hysteresis. Hydrology Earth System Sciences, 20 : 625-632
Mano V, Némery J, Belleudy P & Poirel A (2009) Suspended Particle Matter dynamics in four alpine watersheds (France): influence of climatic regime and optimization of flux calculation. Hydrological Processes 23: 777-792
Misset, C., Recking, A., Legour, C., Poirel, A. & Cazilhac, M. (2018). Geomorphological factors influencing hysteresis patterns between suspended load and flow rate in Alpine rivers. Proc. 9th Int. Conf. on Fluvial Hydraulics, Paquier, A.; Rivière, N. & Khaladi, A. (Eds.) 04404 : 1-8.
Némery J, Mano V, Coynel A, Etcheber H, Moatar F, Meybeck M, Belleudy P & Poirel A (2013) Carbon and suspended sediment transport in an impounded alpine river (Isère, France). Hydrological Processes, 27:2498-2508
Thollet F., Le Coz J., Antoine G., François P. , Saguintaah L., Launay M. & Camenen B. (2013). Influence de la granulométrie des particules sur la mesure par turbidimétrie des flux de matières en suspension dans les cours d'eau, La Houille Blanche, 4:50-56 (in French).