Geomorphic Response and Large Wood Recruitment in the Vésubie Valley (France) Following Storm Alex

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1. Introduction

Wood dynamics in fluvial systems are crucial for ecosystem health and channel morphology but enhance flood hazards when large wood (LW - at least 1m in length and 0.1 m in diameter) accumulates at key cross-sections. LW is mainly recruited during floods from eroded banks, debris flows, and hillslope failures. Research has advanced through monitoring and modeling efforts, estimating LW supply at different scales. However, models often lack integration with the geomorphic activity occurring during floods. Especially in steep, forested catchments, linking geomorphic activity to LW recruitment remains challenging. This study aims to address this gap by examining how channel dynamics influence forest loss and LW input.

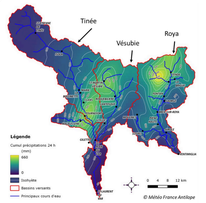
2. Storm Alex and the Vésubie Valley

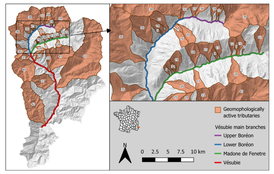
Storm Alex: October 2d - 3rd, 2020

- 502 mm of rainfall in 24h in Saint-Martin-Vésubie
- Rainfall return period > 1000 years (*CEREMA, 2021*)
- Peak discharge at Vésubie outlet (392 km²): 700 - 1100 m³/s
- Discharge return period: 100 - 500 years (*Payrastre et al., 2022*)

Vésubie catchment (south-east France)

- Catchment size: 392 km²
- Tributary of the Var river (sea mouth at Nice)
- Elevation : mean = 1445 m ASL and max = 3143 m ASL
- Crystalline and sedimentary rocks
- Massive glacier deposits from the last glaciation
- Total active channel length: ≈ 150 km
- 43 Active tributaries (size range: 0.06 – 59 km²)





3. Materials and Methods

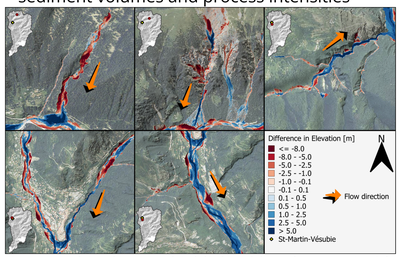
Pre- (2018) and post- event (2020) high-resolution LiDAR point clouds were used for:

Geomorphic changes analyses:

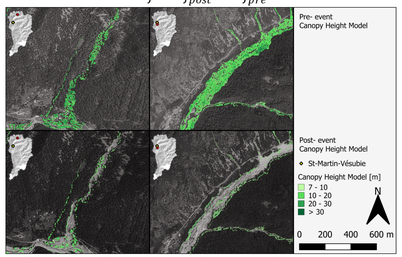
- DTMs resolution 0.5 m
- DEM of Difference (DoD) analysis (*minLoD* = 0.13 m)
- Estimation of geomorphic changes, mobilized sediment volumes and process intensities

Forest cover changes analyses:

- CHM resolution 1 m
- Quantification of the pre- and post-event CHM extension (*Sf*)
- Estimation of the forest cover loss (ΔSf): $\Delta S_f = S_{f_{post}} - S_{f_{pre}}$



Geomorphic changes highlighted by the DoD inside the tributaries (top row) and the main branches (bottom row)



Difference in forest cover between the pre- (top row) and post- (bottom row) event CHMs inside the tributaries (left) and the main branches (right)

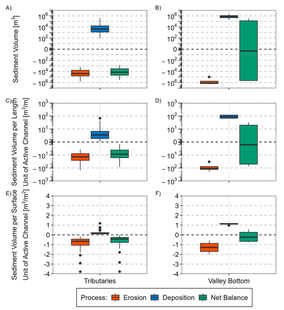
4. Geomorphic changes and large Wood recruitment at (Sub-)Catchment

Storm Alex caused substantial geomorphic changes inside the active tributaries and main branches of the Vésube valley:

- Total volume of erosion = **7.04 Mm³** ± 0.027 Mm³
- Total volume of deposition = **4.90 Mm³** ± 0.022 Mm³
- Negative sediment net balance in every tributary highlight **high connectivity** between tributaries and valley bottoms

Erosion rates per length/surface unit of active channel showed high variability, but highlight the extreme intensities of the debris flows and debris floods triggered by the Storm:

- between **10 m³/m - 50 m³/m** in 23 tributaries
- **> 50 m³/m** in 4 tributaries and in the main branches



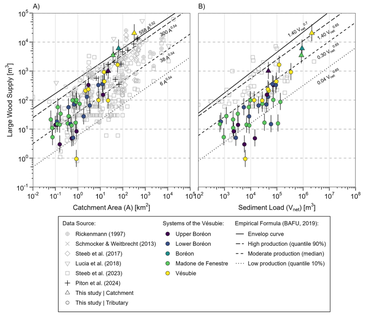
Total forest cover loss: **121 ha**

Tributaries: 0.02 – 10 ha (no forest cover loss in 4 tribs.)

Main branches: 3 - 43 ha

Recruited large wood volumes estimated from the extension of the forest cover loss and forest parameters of the National Forestry Inventory (ONF-IFN):

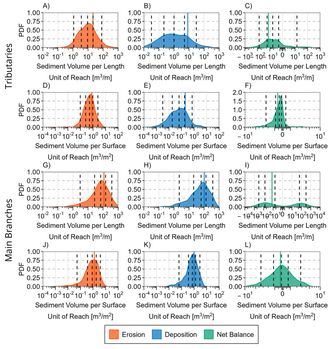
Parameter	Estimations Low (quantile 25 %)	Intermediate (median)	High (quantile 75 %)
Trees per hectare [tree/ha]	242	560	905
Volume of wood per hectare [m³/ha]	89	168	342



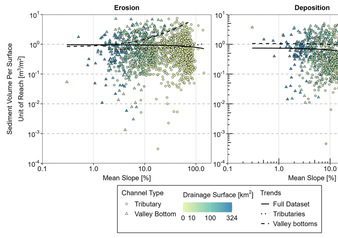
5. Geomorphic changes and large Wood recruitment at reach scale

Segmentation of the geomorphologiacally active areas in **1589 100- m long reaches** (Tributaries: n =1209; Main Branches: n =380)

- High erosion rates and limited sediment storage rates observed in the **tributaries** highlight high **sediment mobility** towards downstram
- High erosion and deposition rates are **consistent** in the **main branches**
- **Erosion intensities** (m³/m²) in the tributaries and the main branches are **comparable**
- **No clear trend** between slope and erosion intensity (m³/m²) was found (p-value = 0.06)
- Slope **highly influence** the deposion intensity (m³/m²) (p-value < 0.001), playing a **major role in sediment connectivity**, although it effect diminishes for decreasing slope



Probability density functions (PDF) of erosion, deposition a net balance volumes per unit of active reach length (A-C, G-I) and surface (D-F, J-L)



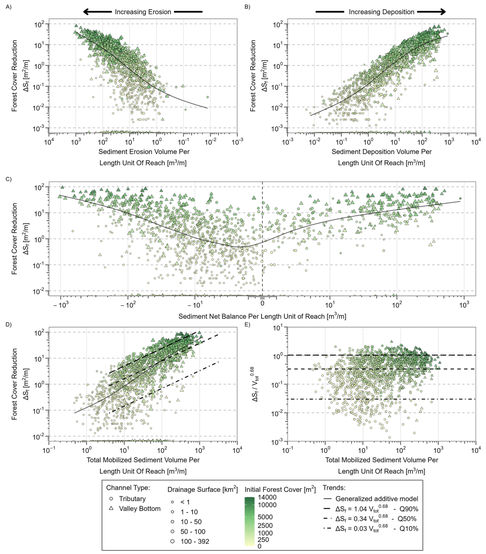
Relationship between sediment volume per unit of reach surface and channel slope inside 100-m reaches.

Forest cover loss was estimated inside the erosional and depositional zones of the reaches by overlapping the pre- and post- event CHM at the DoD:

- **Increasing *ΔSf*** (m²/m) were observed for **increasing erosion and deposition intensities** (m³/m) (p-value< 0.001)
- In 80% of the reaches *ΔSf* is occurring **simultaneously** inside erosional and depositional zones
- Sediment net balance **is not** a good parameter to predict *ΔSf*
- ***Good correlation*** *between* ***increasing ΔSf*** *and* ***increasing total mobilized sediment volume (Vtot)****: 0.77 and 0.73 for Spearman and Pearson respectively*
- *A* ***power- law equation*** *was tested to predict ΔSf as funtion of* V_{tot}: $\Delta S_f' = V_{tot}^{0.68}$

Three equations are provided as the ***10%, 50%, and 90% quantiles*** *of the ratio between ΔSf' and* V_{tot}^{068} *representing an* ***optimistic***, ***intermediate***, *and* ***catastrophic*** *forest cover loss* ***scenarios***

Model	Equations
Best fit (quantile 68%)	$\Delta S_f' = 0.57 \cdot V_{tot}^{0.68}$
Low forest cover loss (quantile 10%)	$\Delta S_f' = 0.03 \cdot V_{tot}^{0.68}$
Intermediate forest cover loss (quantile 50%)	$\Delta S_f' = 0.34 \cdot V_{tot}^{0.68}$
High forest cover loss (quantile 90%)	$\Delta S_f' = 1.04 \cdot V_{tot}^{0.68}$



Relationships between forest cover loss per length unit of reach for: A) intensity of erosion, B) intensity of deposition, C) sediment net balance per length unit of reach, and D) total mobilized sediment volume per length unit of reach. E) Comparison between the ratio ΔSf/V_{tot}^{068} *and the total mobilized sediment volume per length unit of the reach*

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