A hydrodynamic model to comprehend sediment transports in catchments: Focus on Basse-Terre Island

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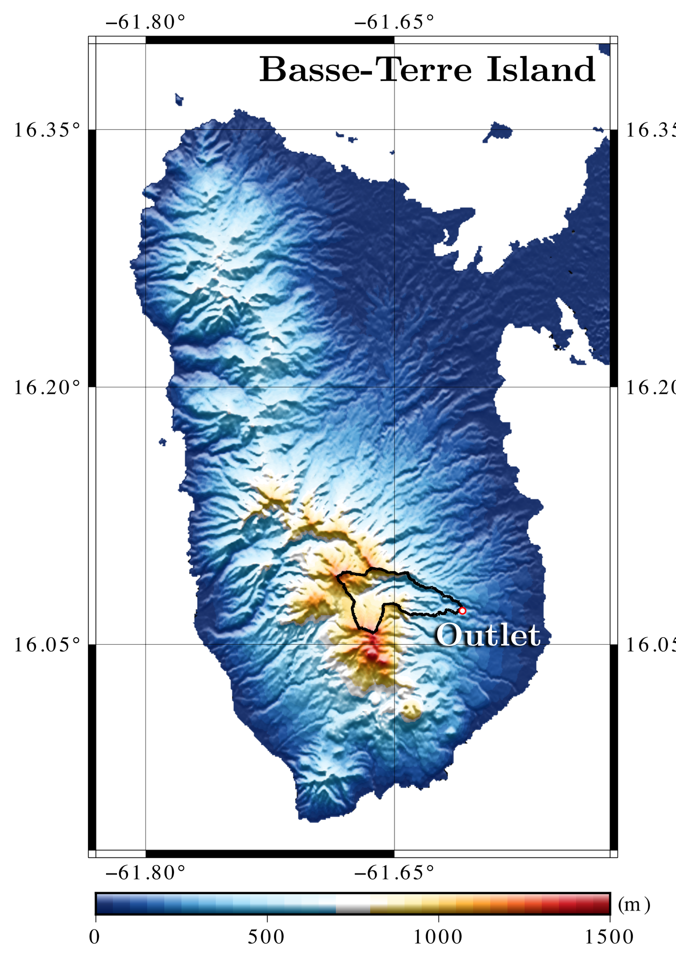
Abstract Mass wasting erodes hillslopes and supplies sediments to catchment rivers (Schuster & Highland, 2007). To assess sediment transports in drainage networks, it is crucial to (1) estimate the volume of sediment delivered to the drainage network, and (2) **evaluate the time needed and processes involved in rivers to evacuate these sediments out of the watershed**. To address these questions, we focus on a catchment located on Basse-Terre Island in Guadeloupe. In this tropical island, **hurricanes and storms generate destructive floods** and mass wasting. The resulting erosion and weathering rates are among the highest on Earth (Allemand et al., 2014; Gaillardet et al., 2011). Using the data collected by the Observatory of Water and Erosion in the Antilles (ObsErA), we **investigate sediment transport in streams at the scale of one flood.** Focusing on the suspended load, we find **that the peak of sediment transport falls** (almost) **systematically behind the discharge peak**. We propose a first order model which accounts for this **hysteretic behaviour**. Using data assimilation, we aim to find the parameters values of the model explaining sediment transport within our catchment. Ultimately, we will assess the response of the alluvial transport to sediment fluxes induced by mass wasting.

I. In situ sensing: catchment, sampling & Calibration

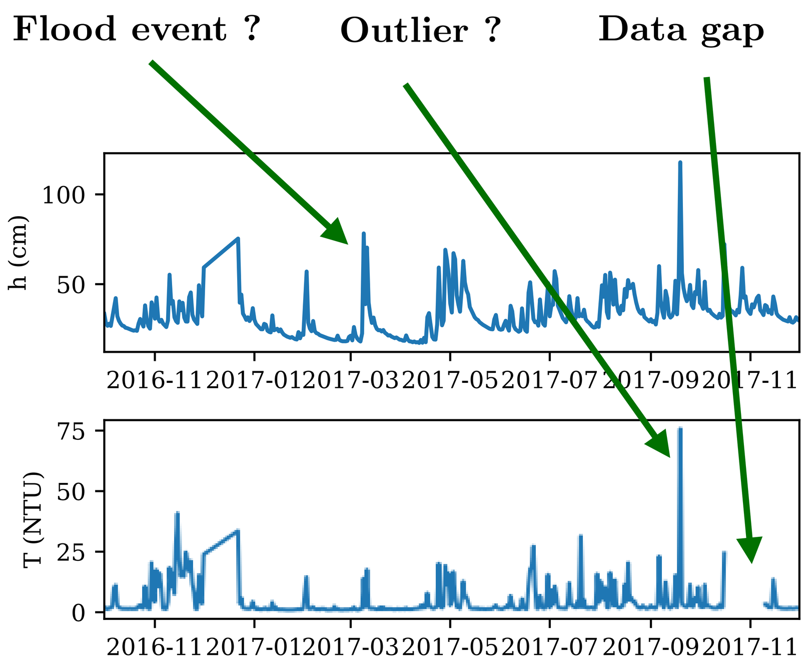
- ***What ?***
  - Understanding how rivers transport sediments
- ***Where ?***
  - Within Capesterre catchment
- ***How ?***
  - By monitoring **hydrology**
    - Water stage h, turbidity T (1pt/5min)
    - Suspended load concentration C_S (manual)



Elevation map of Basse-Terre

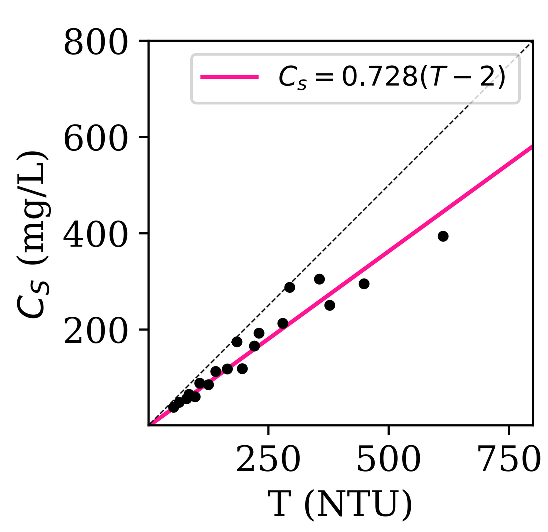
➡ Data clean-up & analyses:
- Events-detection: **floods**

Monitoring set-up



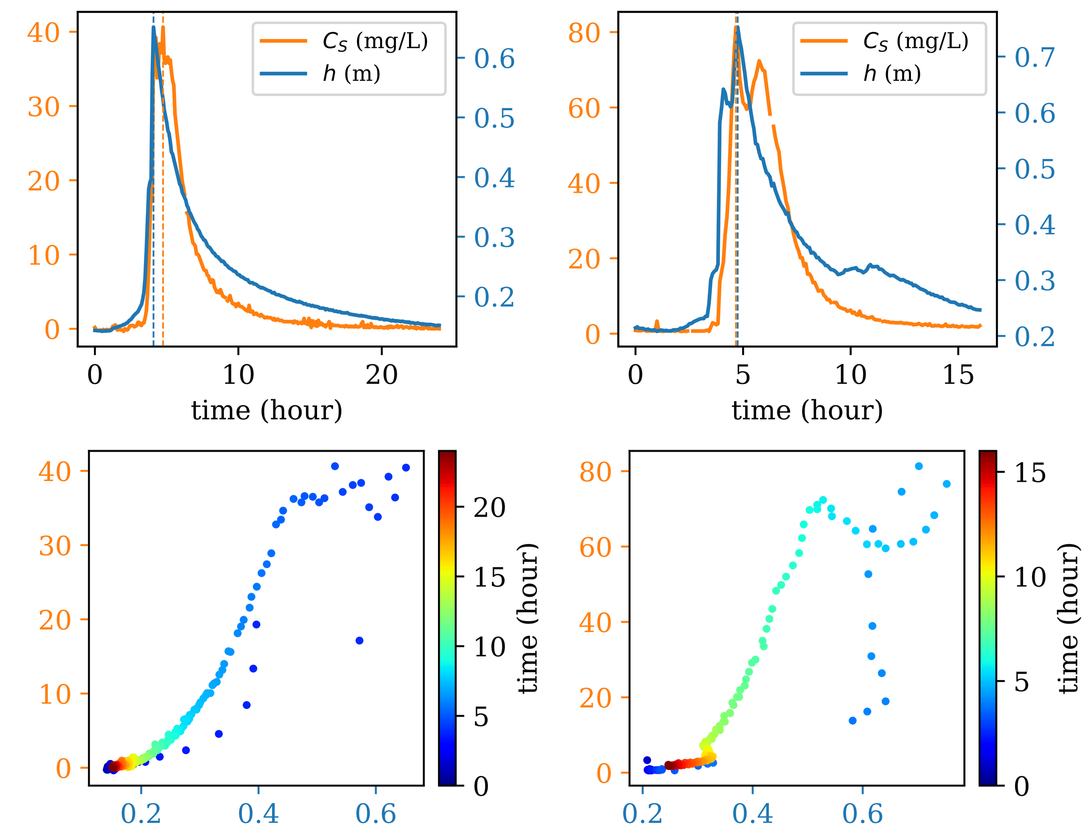
Time series measured by ObsErA

➡ Data calibration



II. Hysteretic behaviours in sediment transport data

- **Shift** between water stage and C_S peaks
- Counter-clockwise and figure-eight **loops**



Examples of floods and hysteretic cycles measured by ObsErA

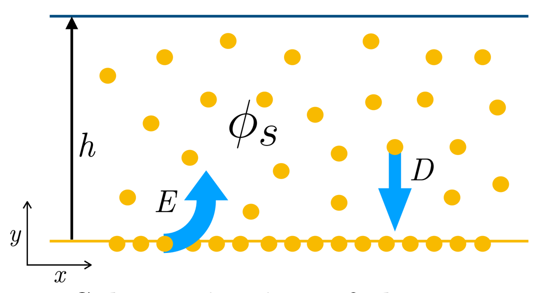
◉ **How to explain such behaviour ?**
- By **modelling** what happens in the river

III. Hydrodynamic modelling of sediment transport hysteresis

Quantity	Variable	Dimension
Water Level	h, h_t, $\tilde{h}$	L, L, none
Suspended load	ϕ_s	M/L^2
Flow Velocity	U	L/T
Erosion	E	M/L^2/T
Erosion rate	ϵ	M/L^2/T
Deposition	D	M/L^2/T
Deposition time	τ_D	T

a. **Theoretical framework**

Two processes:
Erosion E & Deposition D



Schematisation of the set up

$$\frac{d\phi_s}{dt} = E - D$$

c. **Hypotheses** (river-based)

i. $E \propto$ shear stress
   shear stress $\propto h,\ h_t$
   —> $\boldsymbol{E \propto h,\ h_t}$

ii. D
   - Cst with y and t
   - Stockes' law

$$D \propto \frac{U\phi_s}{h}$$

d. **Final equation**

$$\frac{d\phi_s}{dt} = \epsilon\left(\tilde{h}-1\right) H\left(\tilde{h}-1\right) - \frac{1}{\tau_D}\frac{\phi_s}{\tilde{h}}$$

$$C_S = \phi_S / h$$

e. **Parameters**

- Water level
- Water level threshold h_t
- Erosion rate
- Deposition time

◉ **How to find their values ?**
- Using data assimilation
  - **Erosion rate**
  - **Deposition time**

IV. Data assimilation to determine the erosion rate, water level threshold and deposition time of a hysteresis

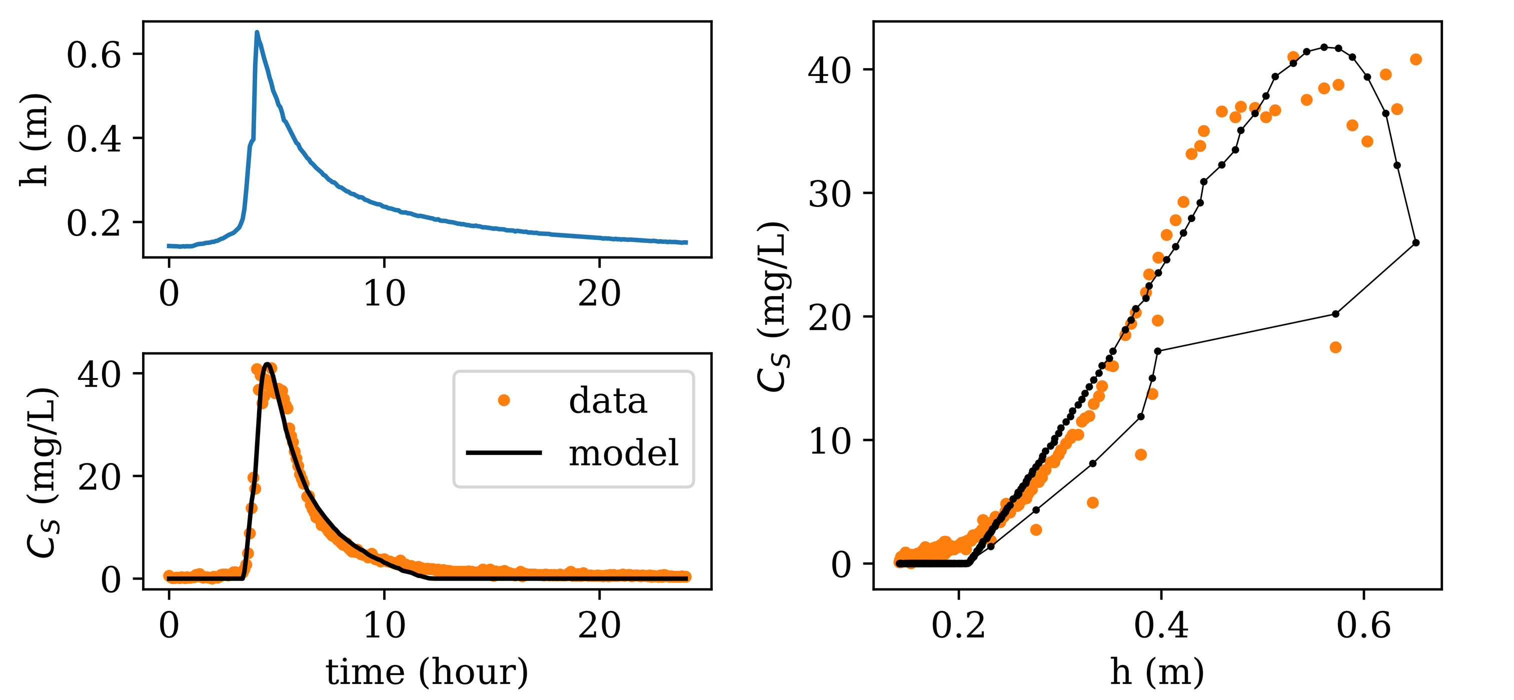
- Method: python scipy curve fitting
- Best fit parameters output:

Parameter	Estimate
h_t	0.21 m
ϵ	1.5 10^{-2} g.m^{-2}.s^{-1}
τ_D	325 s

- Parameters bounds:

Range	Unit
$0.1 < h_t < 0.5$	m
$0 < \epsilon < 50$	g.m^{-2}.s^{-1}
$1 < \tau_D < 7200$	s

Best fit results. Both cycles are counter-clockwise.

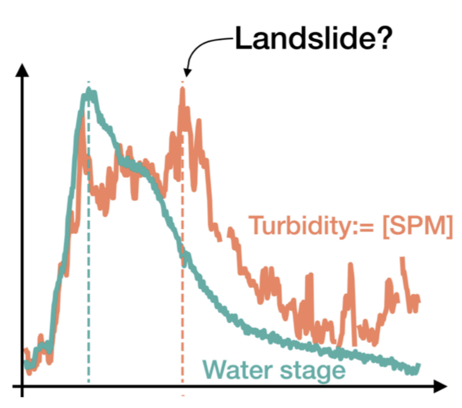


Next:
- Tests on other data sets
- Include uncertainties

V. Conclusion

- **Parameters derived from the model are consistent with expectations**
- But the model cannot produce double-peak C_S —> what causes it ?

—> find out with remote sensing



VI. Perspectives: remote Sensing

➡ Determination of
- Landslide sources, repartition
- Volumes —> Fluxes in time and space
- Gradient effects : Rainfall (E-W) & Lithology (N-S)

References

Allemand et al., 2014, *Erosive effects of the storm Helena (1963) on Basse Terre Island (Guadeloupe — Lesser Antilles Arc)*
Gaillardet et al., 2011, *Orography-driven chemical denudation in the Lesser Antilles: evidence for a new feed-back mechanism stabilising atmospheric CO2*
Schuster & Highland, 2007, *Overview of the Effects of Mass Wasting on the Natural Environment*