Retrieving avalanche basal friction law from high rate positioning of avalanches

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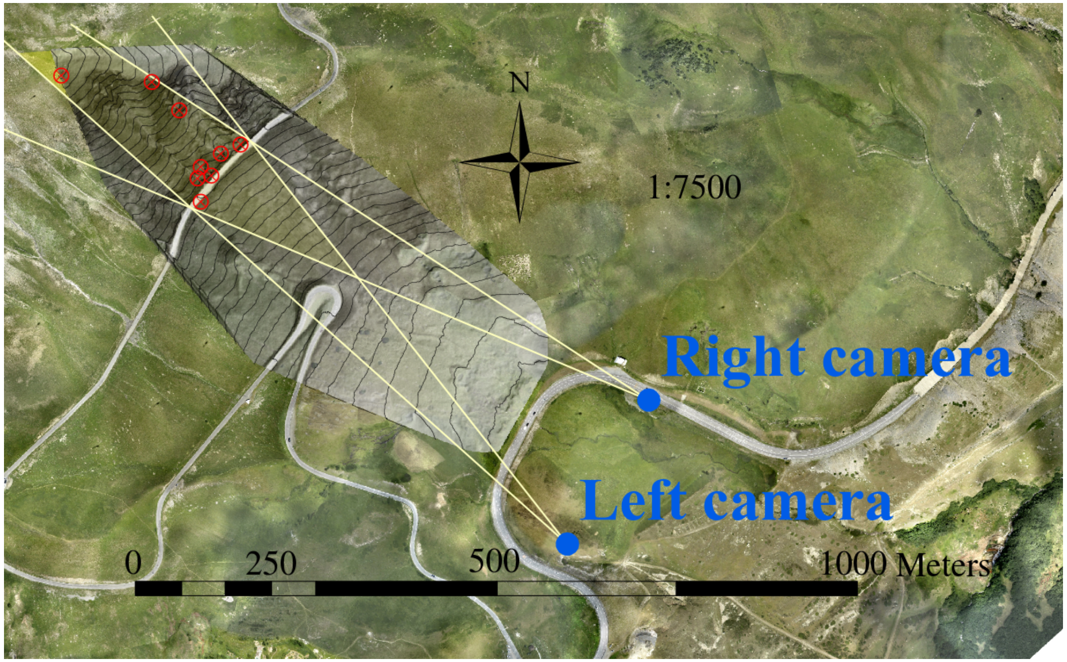
European Geosciences Union General Assembly 2015
Vienna | Austria | 12 – 17 April 2015

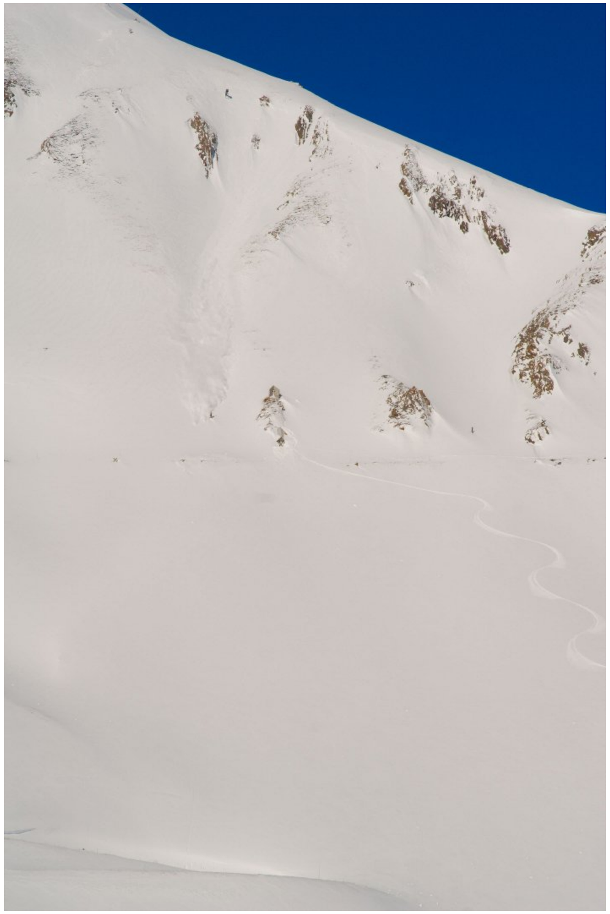
Lautaret test site

Small avalanches : V = 10^2-10^3 m^3

Length of the path : 800m

Artificially released avalanches

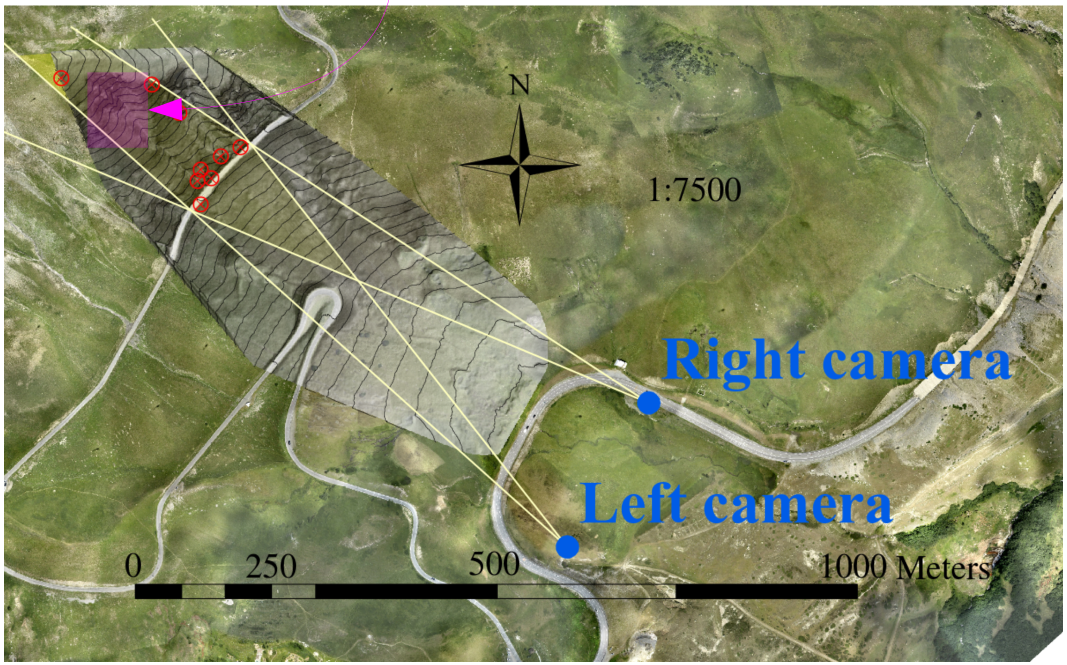




Lautaret test site

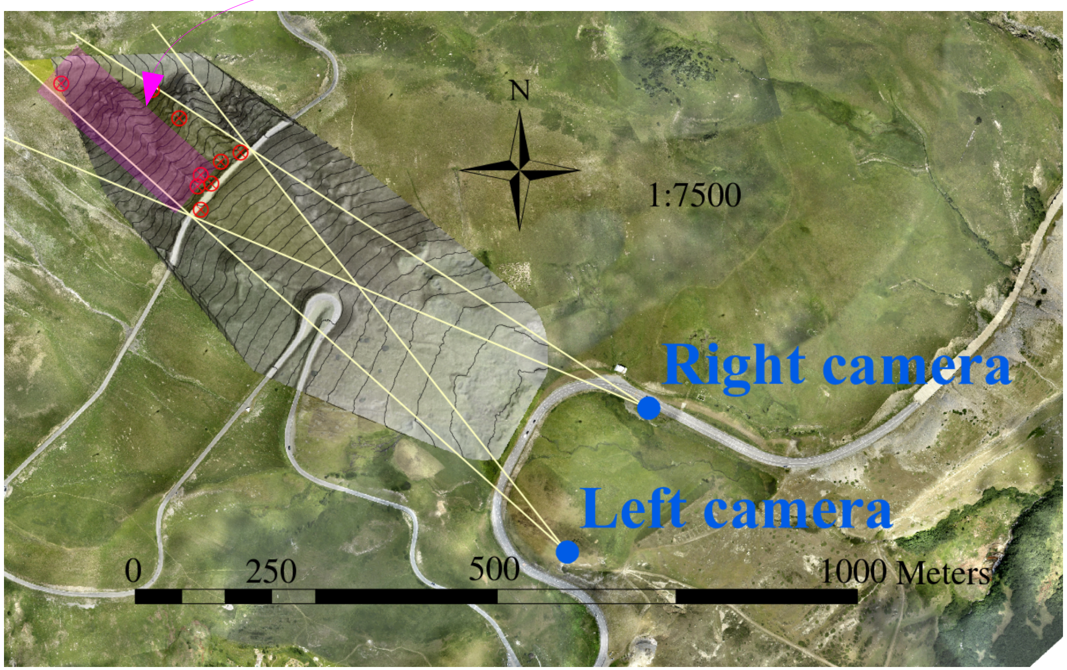
Trigger using a Gazex®

Release area



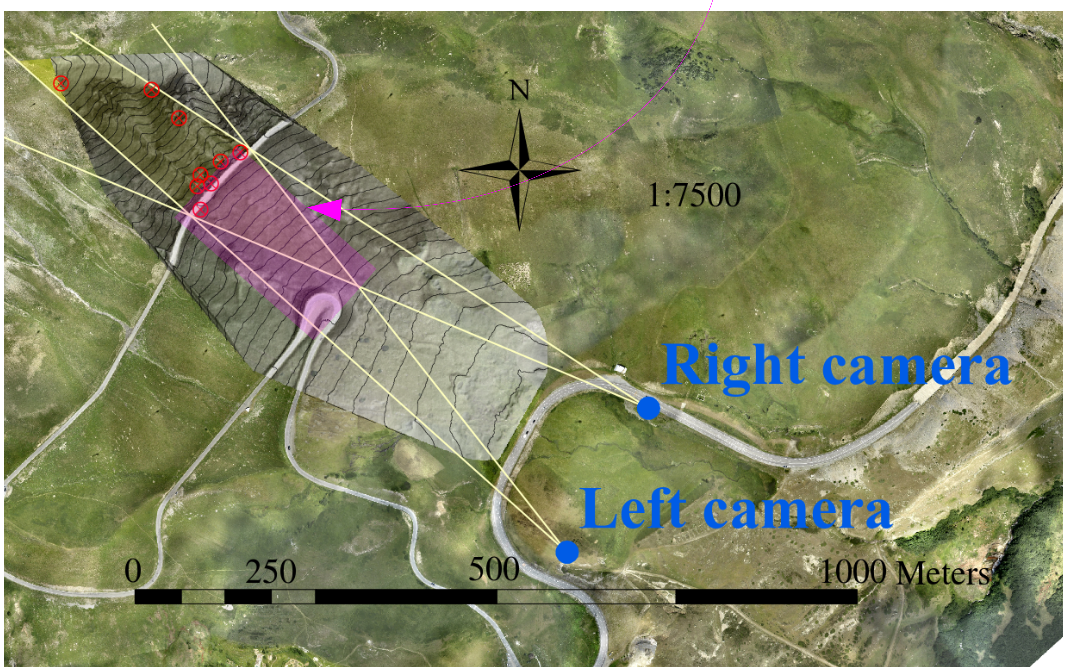
Lautaret test site

Accelerate part of the flow (channelize): <α> = 37°



Lautaret test site

Run out Zone: <α> = 30°

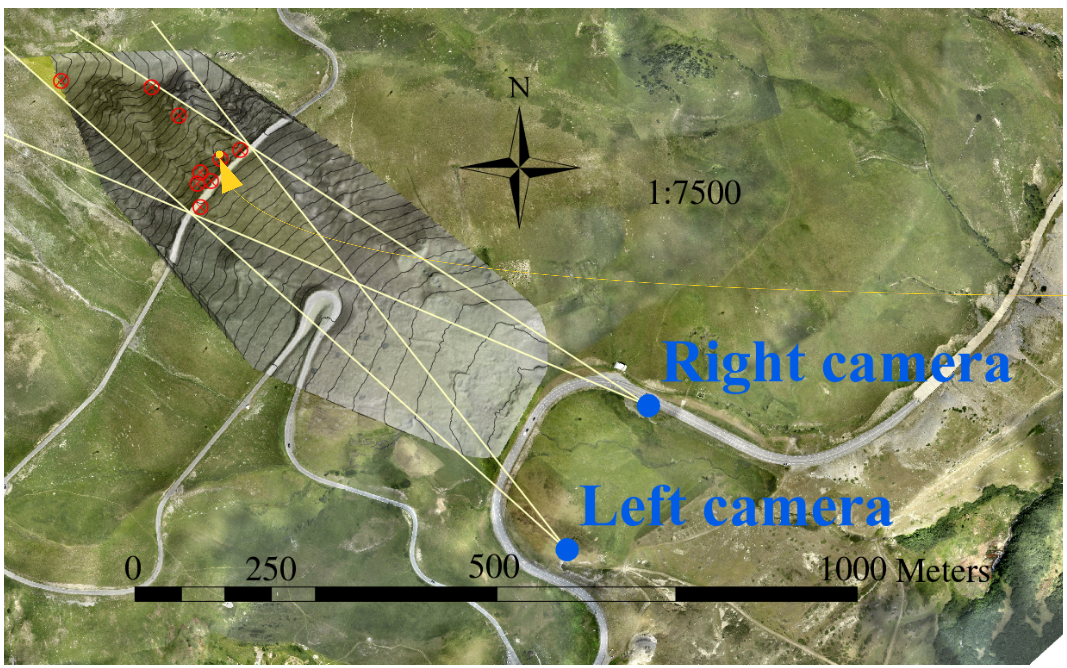


Lautaret test site

Track the avalanche front → using photogrammetry

2 APS-C DSLR + 85mm lens

Synchronise acquisition of images at 1fps



Couple of image

Area of measurement

Obtain the 3D position of the avalanche front each second

Method: preliminary 1D process

Photogrammetry (3D front position)	Calculate the centroid position	$V = f(c)$ c: curvilinear abscissa

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Photogrammetry (3D front position)

Calculate the centroid position

$V = f(c)$
c: curvilinear abscissa

↓

Sliding block model (derive from the momentum equation)

Voelmy's Friction law
$\mu = f(\mu_0, \xi)$

Method: preliminary 1D process

Photogrammetry (3D front position)

Calculate the centroid position

V = f(c)
c: curvilinear abscissa

↓

Sliding block model (derive from the momentum equation)

Voelmy's Friction law
$\mu = f(\mu_0, \xi)$

↓

$V = f(\mu_0, \xi, c)$

↓

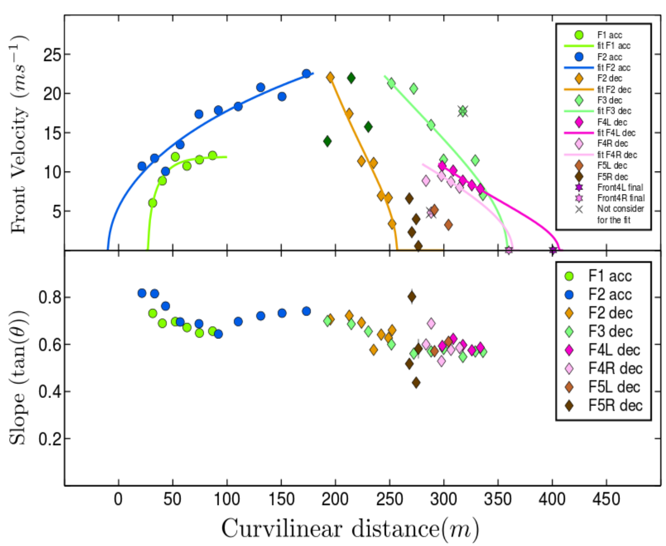
Fit the data :
μ_0, ξ

Result

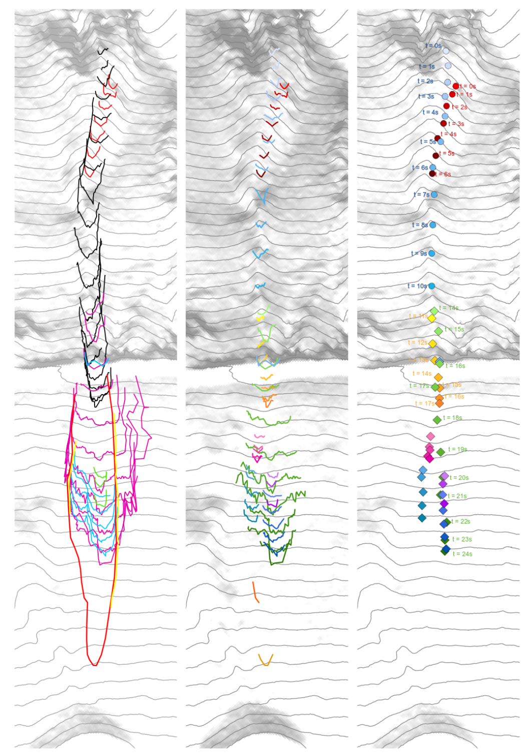
3 avalanches measured and analysed :
- March 2nd 2010
- December 19h 2012
- February 13th 2013

6 couple of data obtain for the accelerate flow

5 couple of data for the decelerate flow



Complex flow can be study thanks to the photo-interpretation



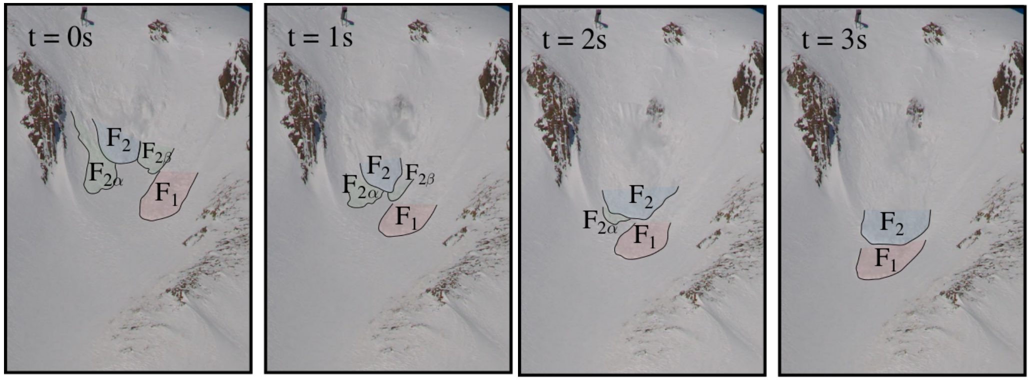
Accurate measurement: photogrammetry

Accurate measurement :

- High resolution of images (4288x2848pix).
- High quality lens 85mm f/1.4 AF-S series D Nikon.
- Low theoretical error of the measurement: Std = 23cm
- Image orientations made with ORIMA software using 9 GCP.
- 2 cameras synchronised by cable and triggered using the master clock of a Campbell CR3000 micro logger ($\sigma_t = 5.6 \times 10^{-6}$s).

Photo-interpretation :

→ Multiple surge during one events can be measured.



3 Avalanches at Col du Lautaret

- <u>March 2nd 2010</u>

  → First data from photogrammetry

  Problem with the for synchronise the 2 camera (solve for the next)

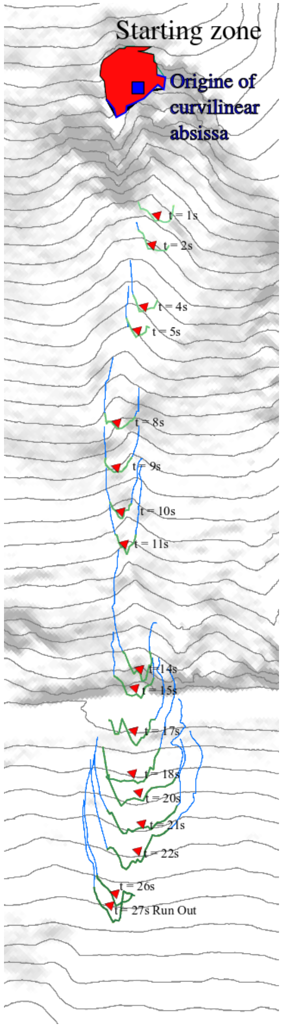
- <u>December 19th 2012</u>

  → cold snow (important powder cloud → hide the dense front)

- <u>February 13th 2013</u>

  → Multiple surges, complex avalanche but lots of data

March 2nd 2010



Process apply for the Centroid calculation :

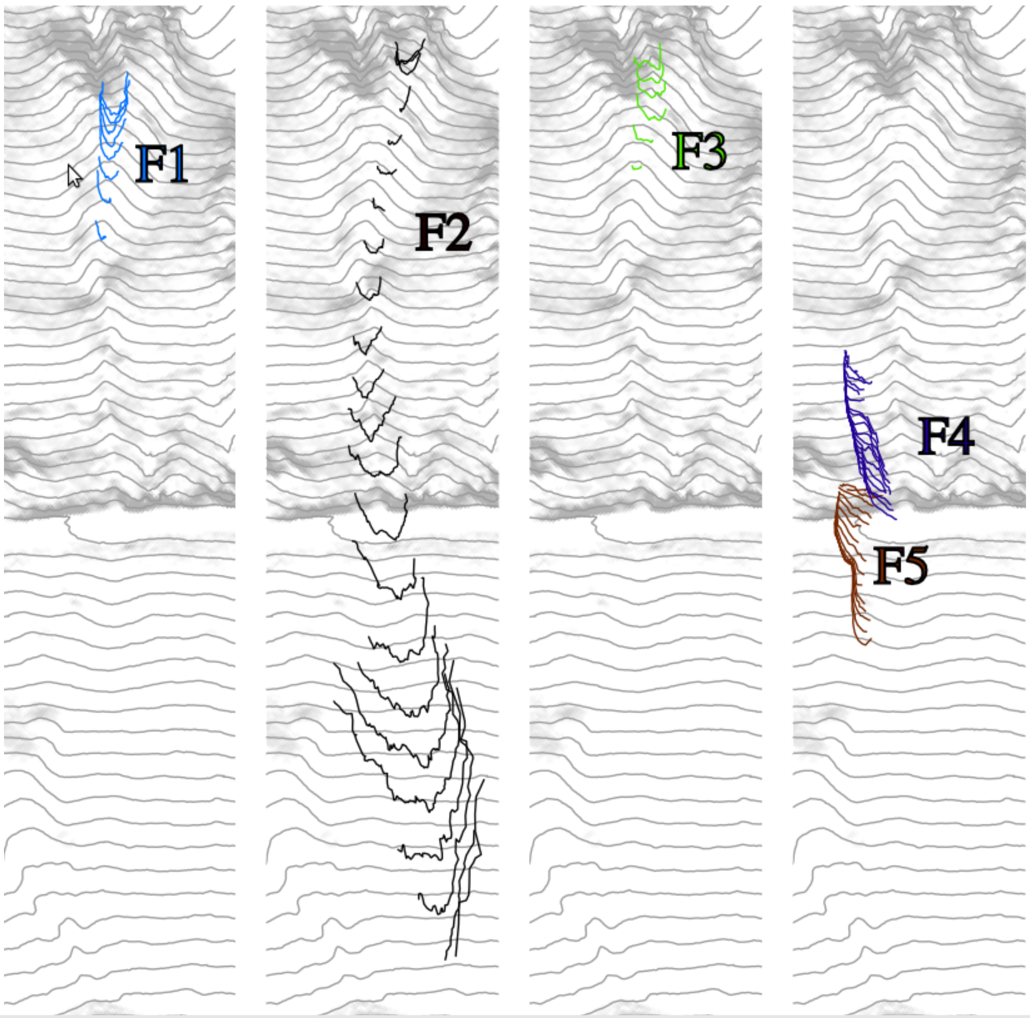
1) Get the data from the photogrammetry (blue line).

2) Select the active part of the front (green line).

3) Calculate the centroid as (red triangle):

$$\bar{C_f} = \left[\sum_{i=0}^{n} x_i \; ; \; \sum_{i=0}^{n} y_i \; ; \; \sum_{i=0}^{n} z_i \right]^T$$

December 19th 2012



One main flow: → F2

Two small surge in the release area:
→ F1/F3

2 slab at side of the avalanches:
→ F4/F5

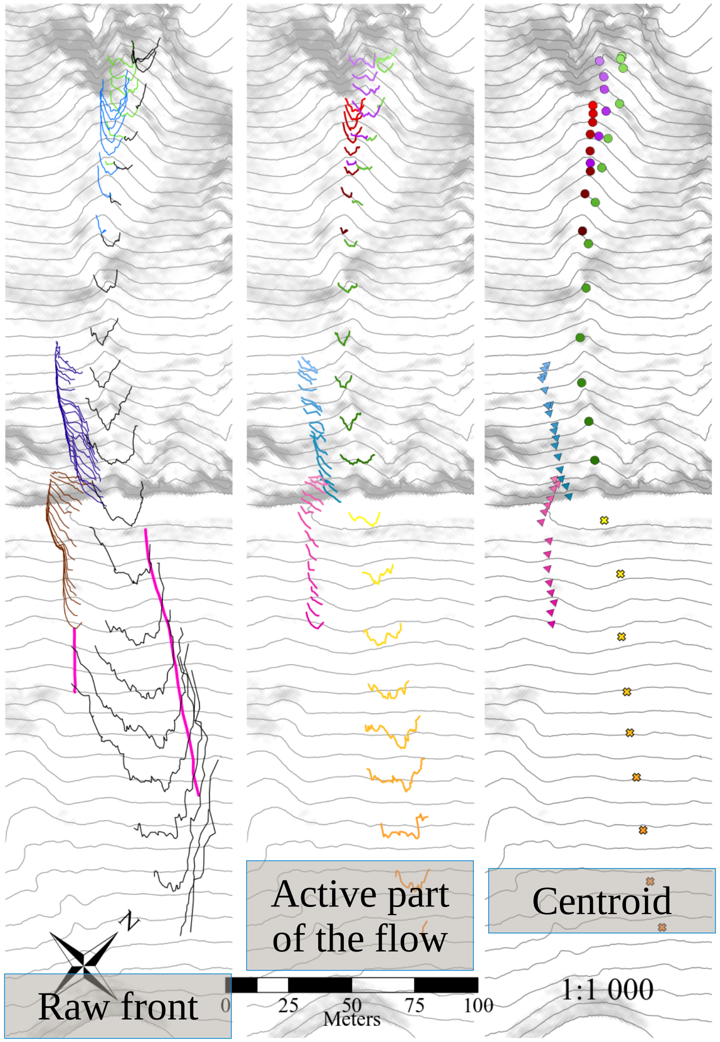
December 19th 2012

Step for the centroid calculation:

a) Raw front

b) Active part of the flow

c) Centroid



February 13th 2013

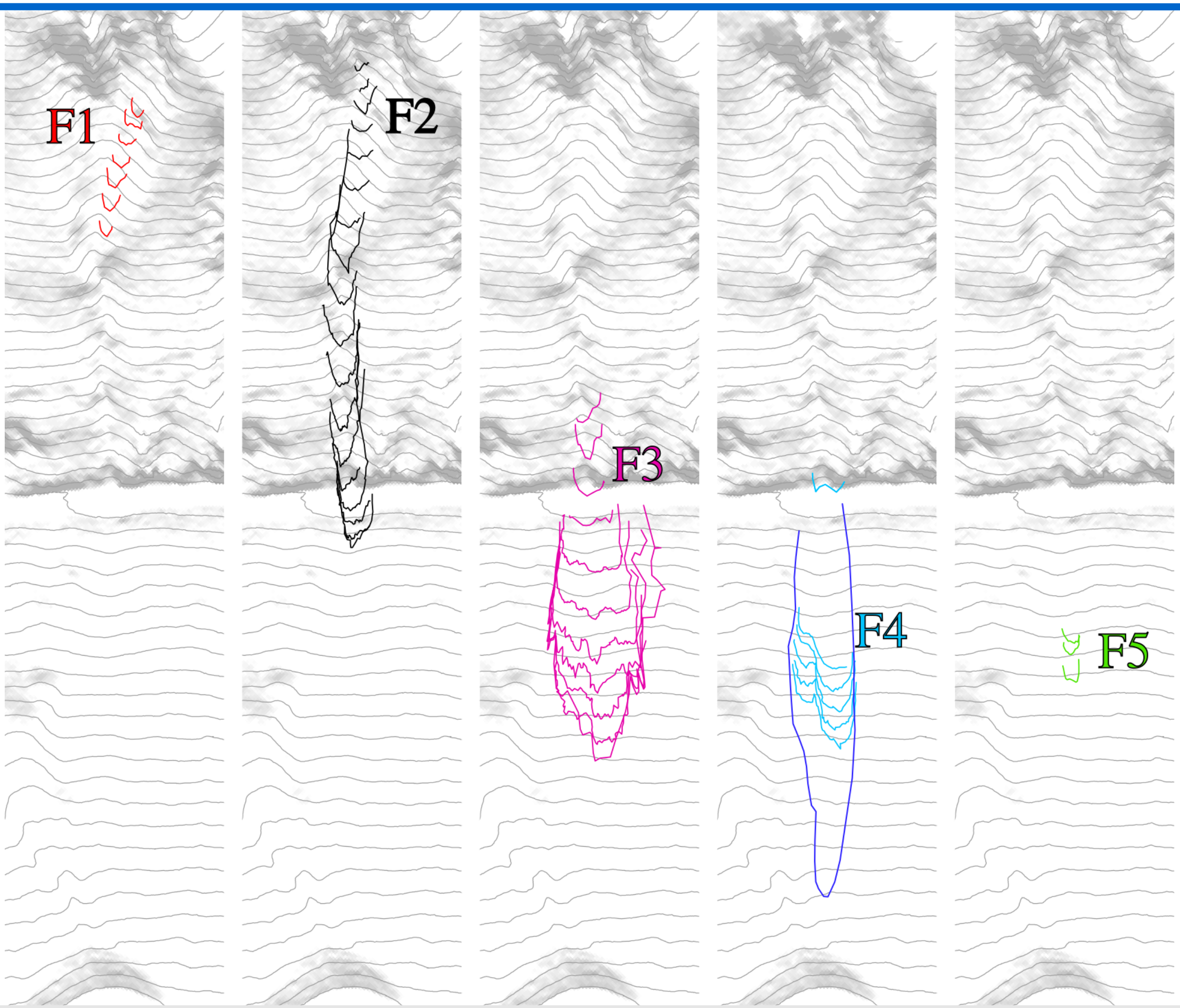
One small flow in the release area:
→ F1 (merge with F2 after 7s).

F2 main flow: Accelerate, and stop quickly.

F3 Run out of a surge cover by some fluidise snow.

F4 dense and slow flow. Generate the main deposit. 2 parts can be detected: → F4R/F4L.

F5 secondary surge over the main deposit.



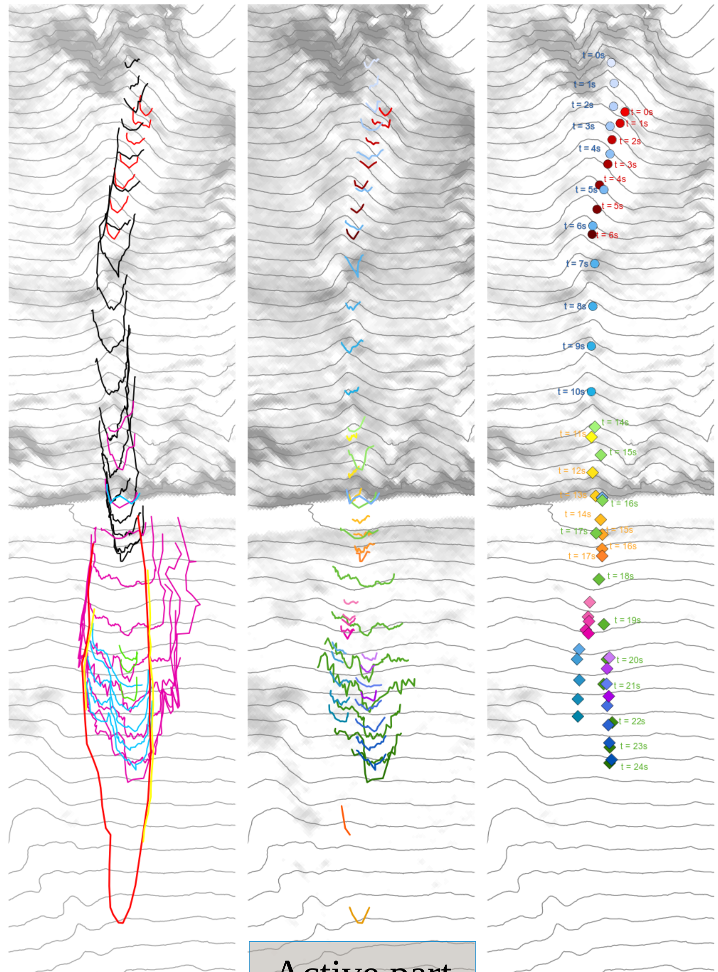
February 13th 2013

Step for the centroid calculation:

a) Raw front

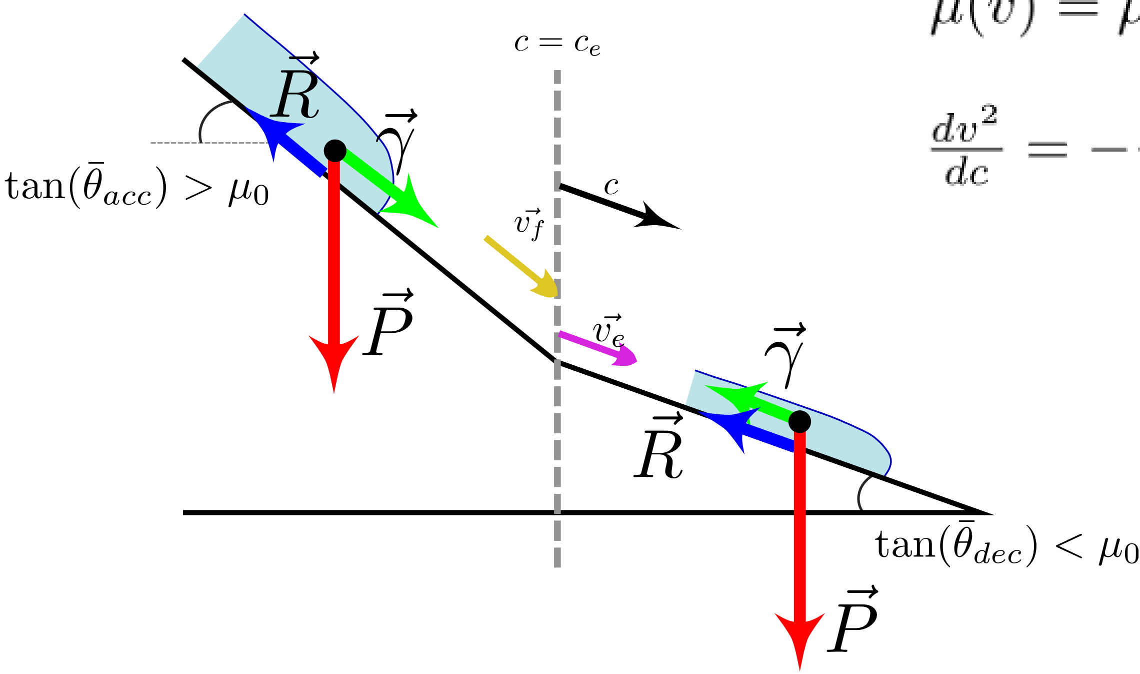
b) Active part of the flow

c) Centroid



Raw front | Active part of the flow | Centroid

Model: General equations



$$\rho V \frac{d\vec{v}}{dt} = \vec{P} + \vec{R}$$

$$\rho V \frac{dv(c)}{dt} = \rho V g \sin(\theta) - \rho V g \cos(\theta) \mu(v(c))$$

$$\mu(v) = \mu_0 + \frac{g}{\xi}(F_r^2) \text{ with } F_r = \frac{v}{\sqrt{gh}}$$

$$\frac{dv^2}{dc} = -\frac{2g}{\xi h} \cos(\theta) \left[\xi h (\tan(\theta) - \mu_0) - v(c)^2\right]$$

Model: Velocity a function of curvilinear abscissa

Accelerated part of flow

$$v(c) = v_f \sqrt{1 - \exp\left(-\frac{2g}{\xi h}\cos(\bar{\theta}_{acc})(c - c_0)\right)}$$

$$v_f = \sqrt{\xi h(\tan(\bar{\theta}_{acc}) - \mu_0)}$$

Decelerated part of flow

$$v(c) = \sqrt{-v_1^2 + (v_1^2 + v_e^2)\exp\left(-\frac{2g}{\xi h}\cos(\bar{\theta}_{dec})(c - c_e)\right)}$$

$$v_1 = \sqrt{\xi h(\mu_0 - \tan(\bar{\theta}_{dec}))}$$

Model: How to determine sliding parameter

Fit the data obtain by photogrammetry

Matlab fiting toolbox

Accelerated part of flow

$$v = \alpha\sqrt{1 - \exp\left(-\beta(c - c_0)\right)}$$

$$\mu_{0acc} = \tan(\bar{\theta}_{acc}) - \frac{\alpha^2\beta}{2g\cos(\bar{\theta}_{acc})}$$

$$(\xi h)_{acc} = \frac{2g\cos(\bar{\theta}_{acc})}{\beta}$$

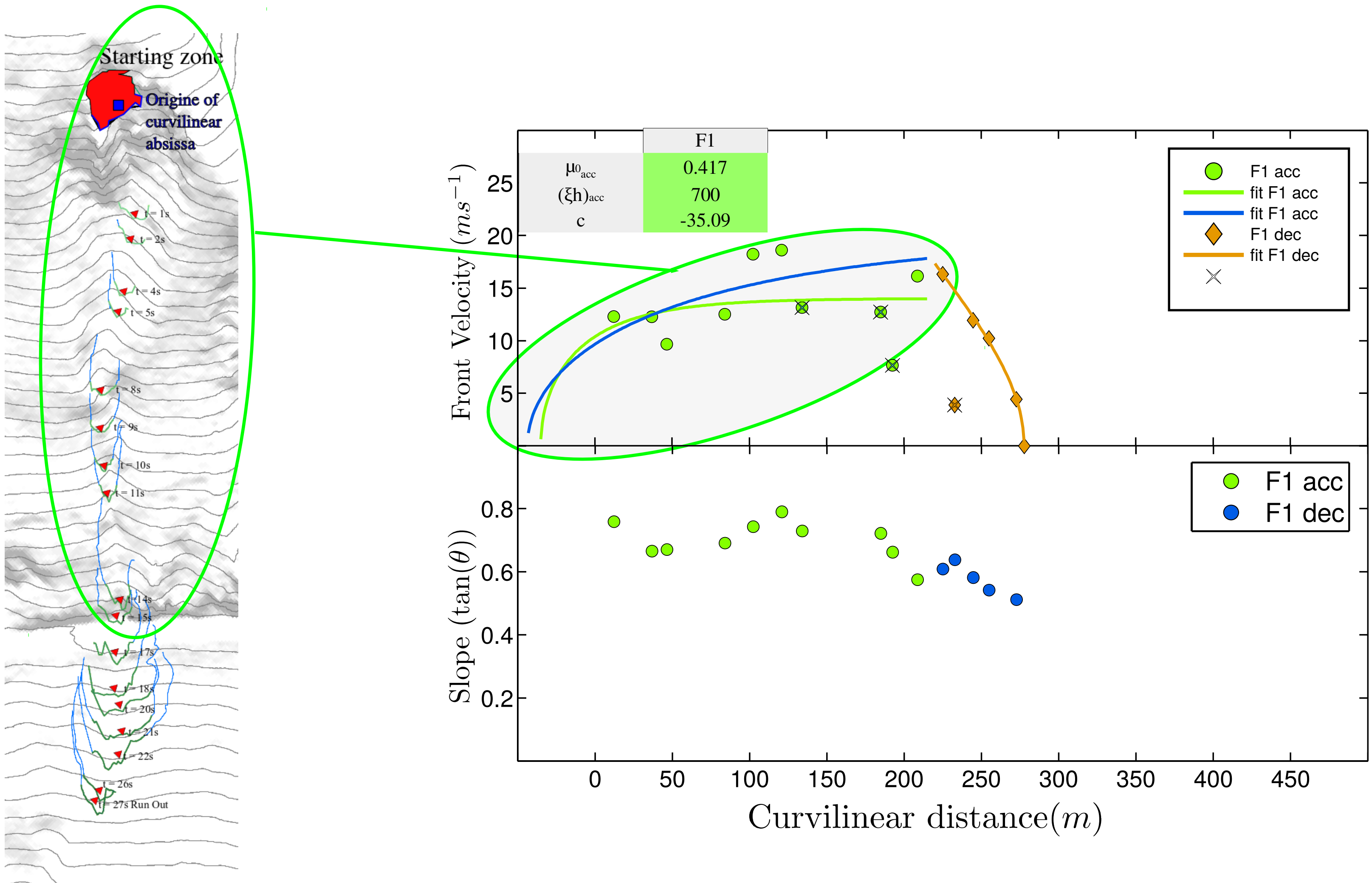
Decelerated part of flow

$$v = \sqrt{-\gamma + (\gamma + v_e^2)\exp\left(-\delta(c - c_e)\right)}$$

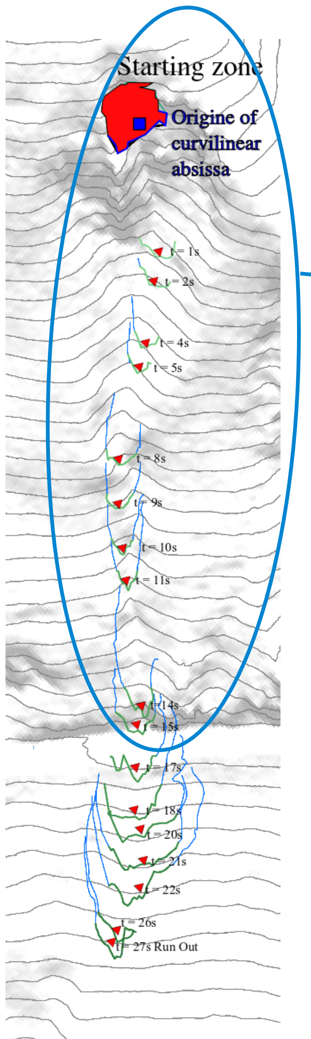
$$(\xi h)_{dec} = \frac{2g\cos(\bar{\theta}_{dec})}{\delta}$$

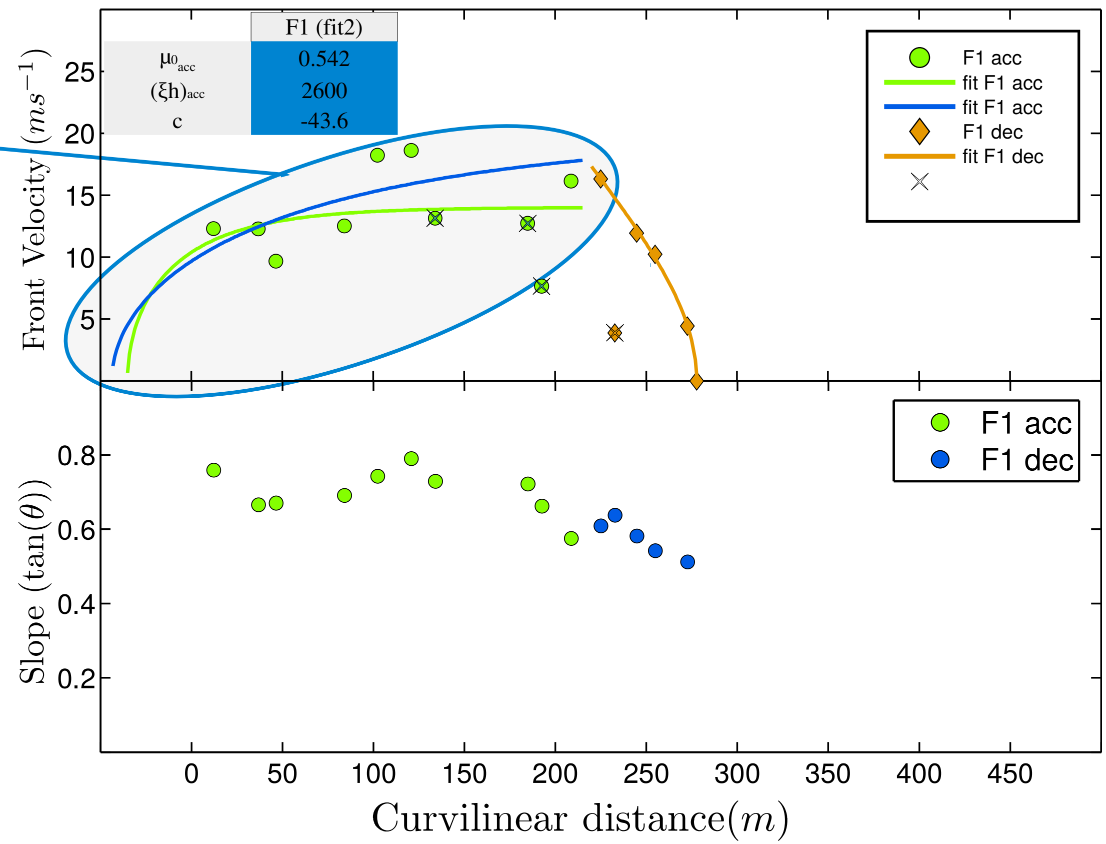
$$\mu_{0dec} = \tan(\bar{\theta}_{dec}) + \frac{\gamma\delta}{2g\cos(\bar{\theta}_{dec})}$$

Sliding parameter : March 2nd 2010

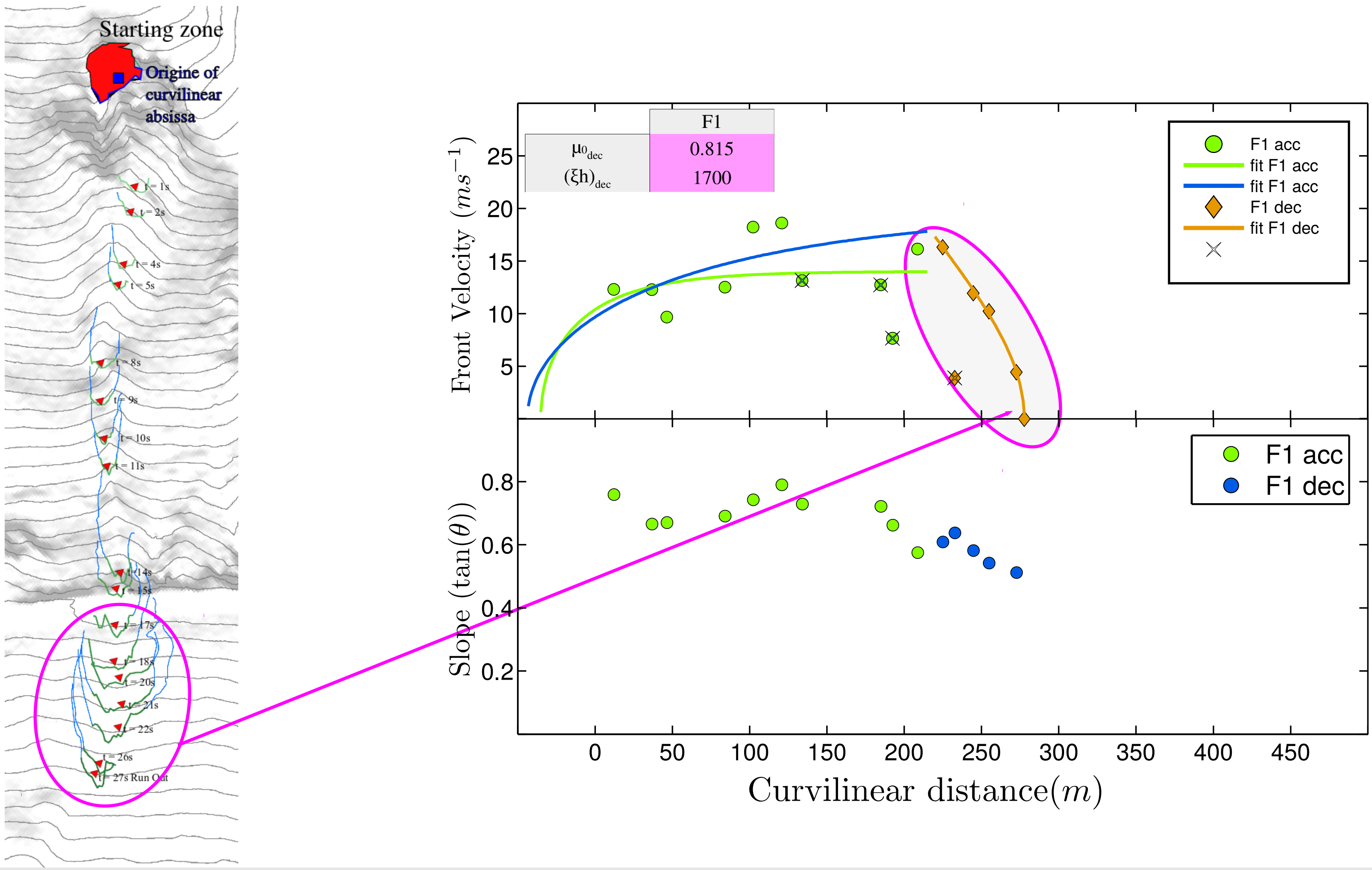


Sliding parameter : March 2nd 2010

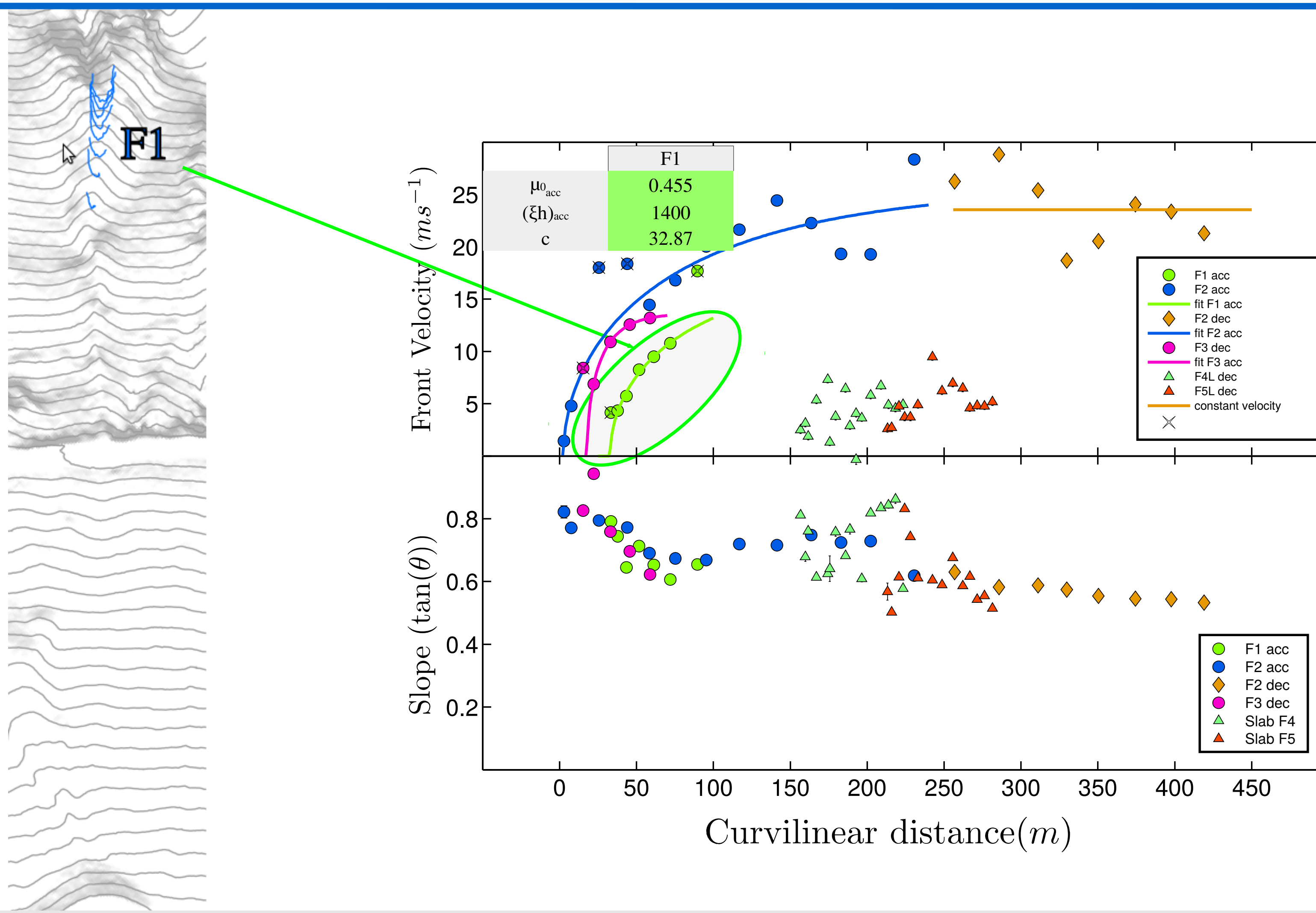




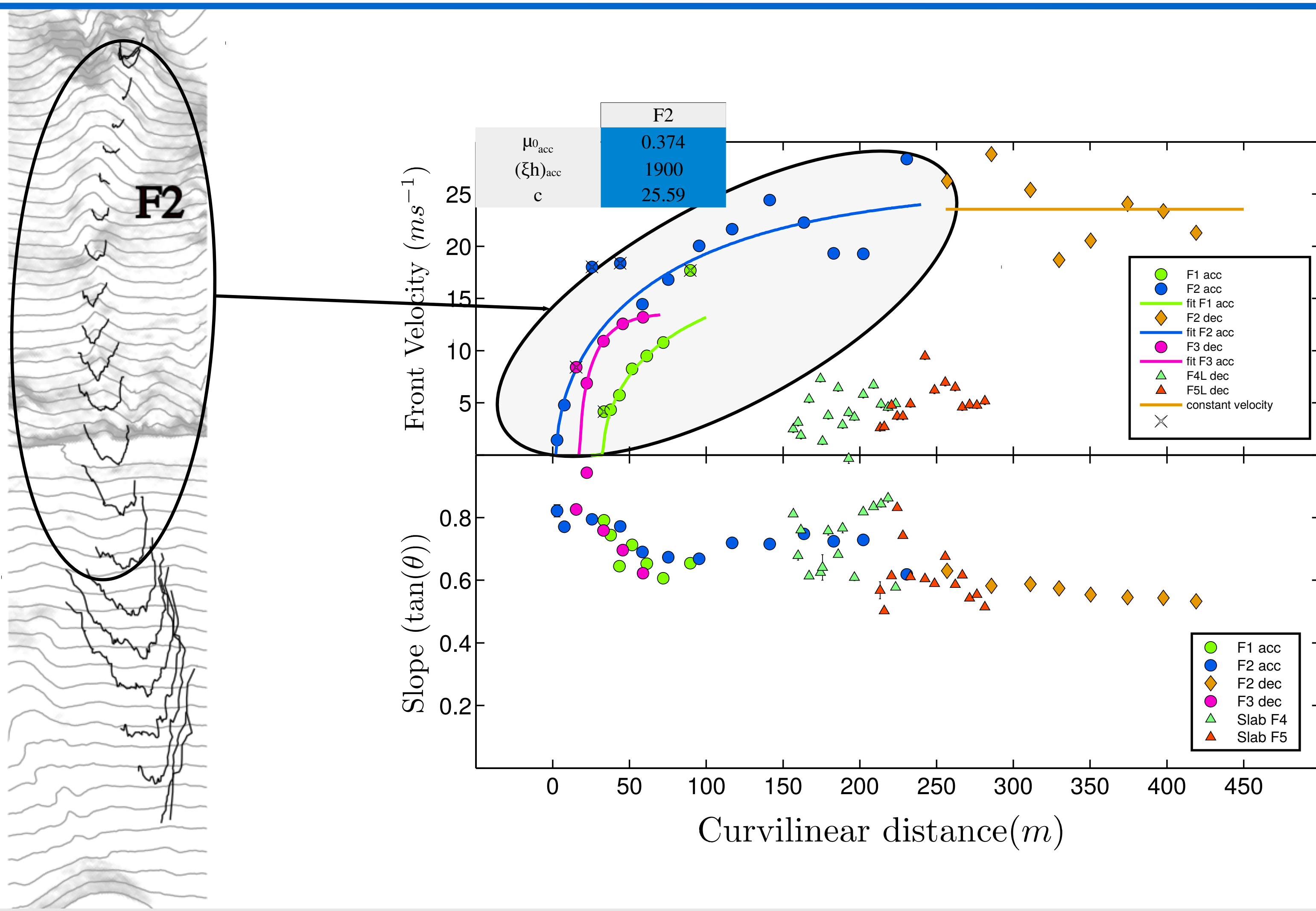
Sliding parameter : March 2nd 2010



Sliding parameter : December 19th 2012

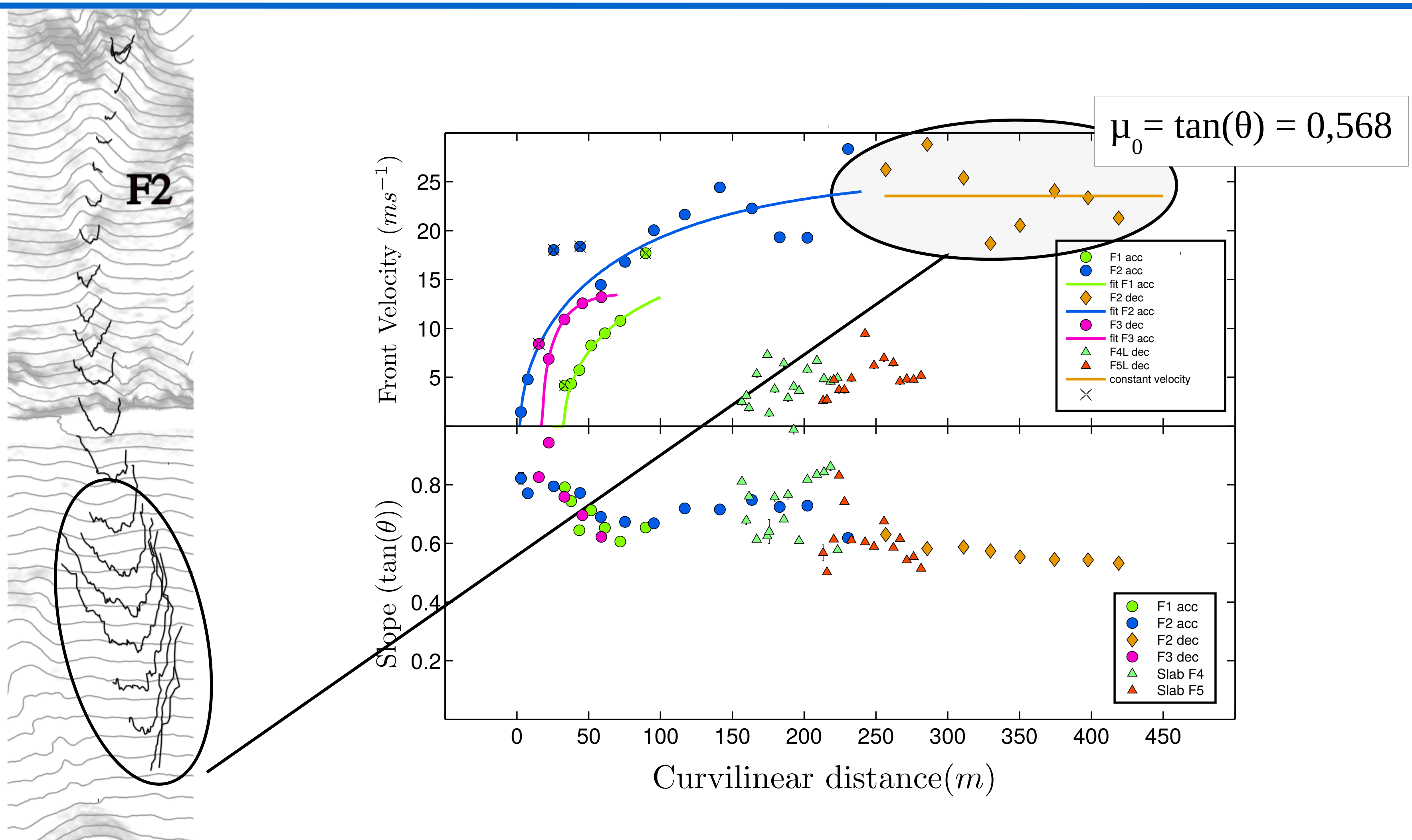


Sliding parameter : December 19th 2012

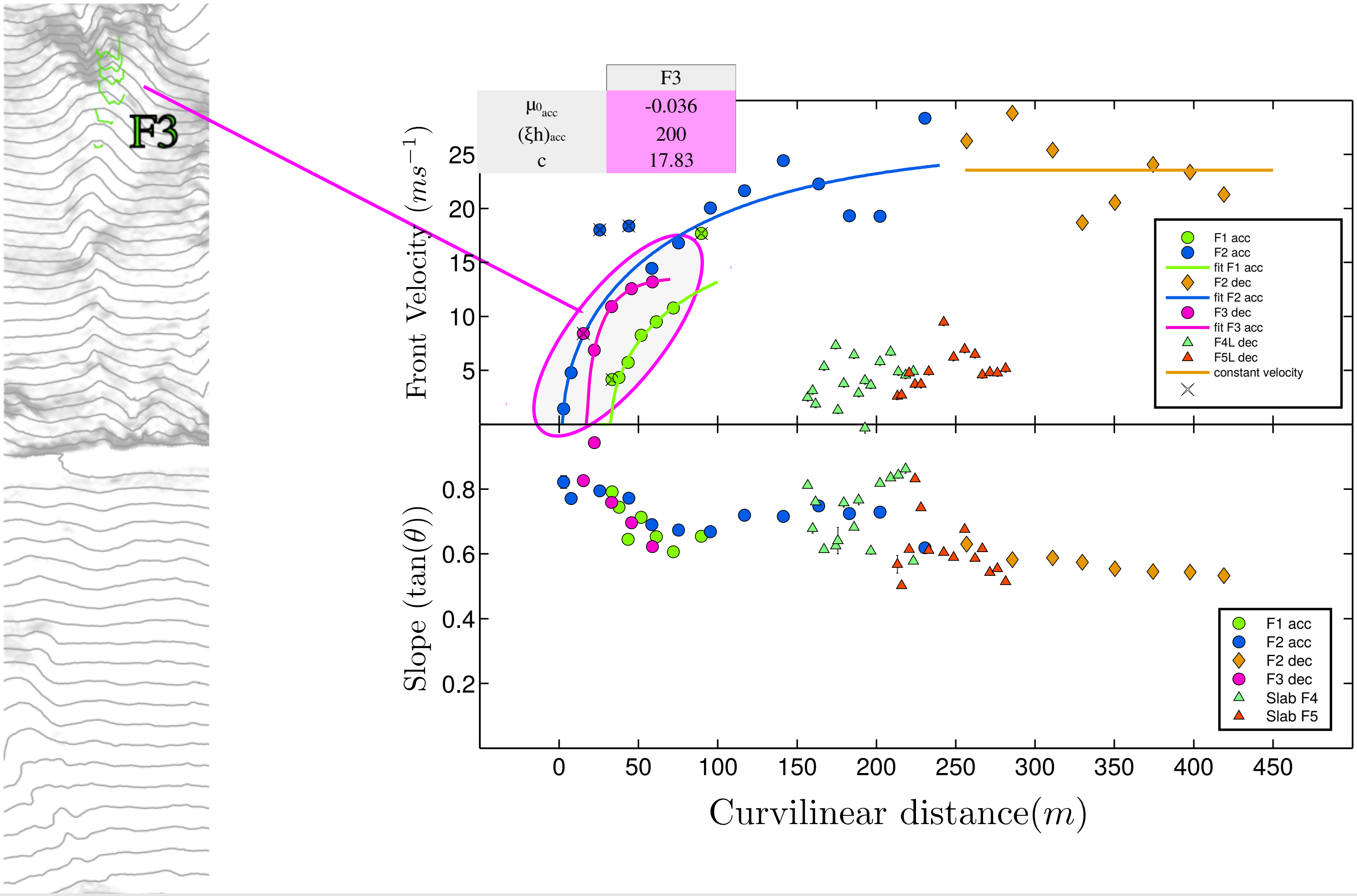


	F2
$\mu_{0_{acc}}$	0.374
$(\xi h)_{acc}$	1900
c	25.59

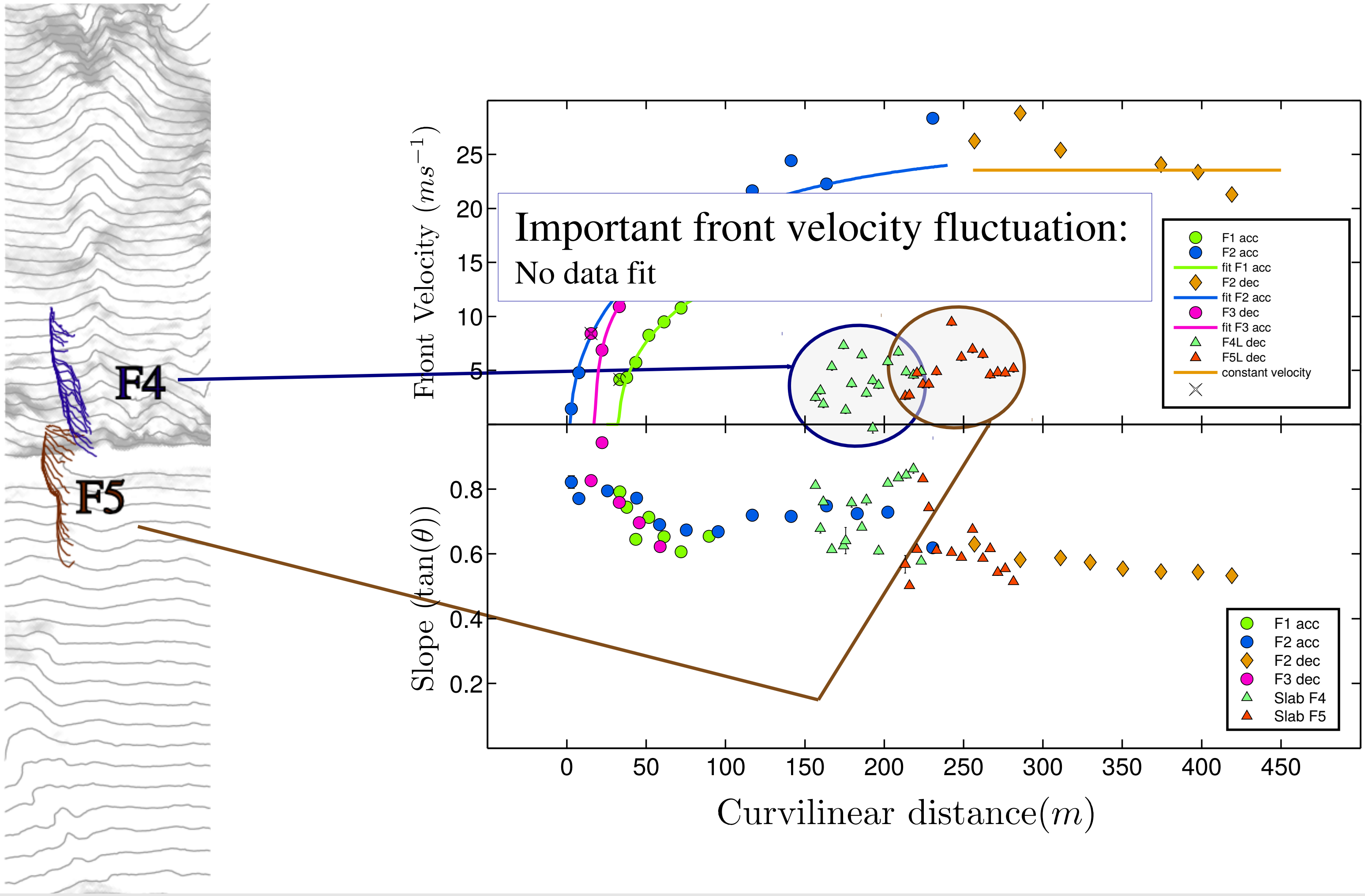
Sliding parameter : December 19th 2012



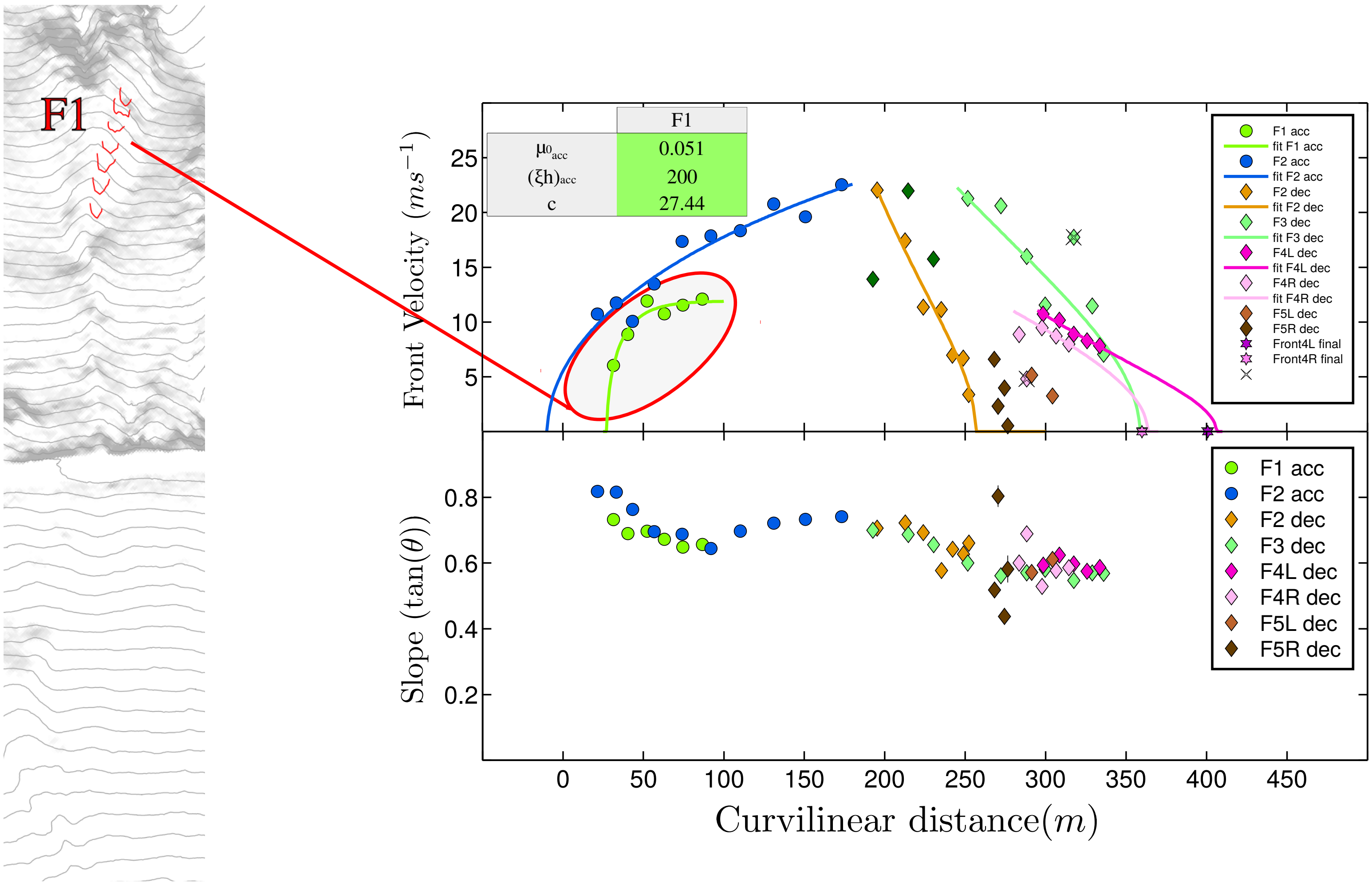
Sliding parameter : December 19th 2012



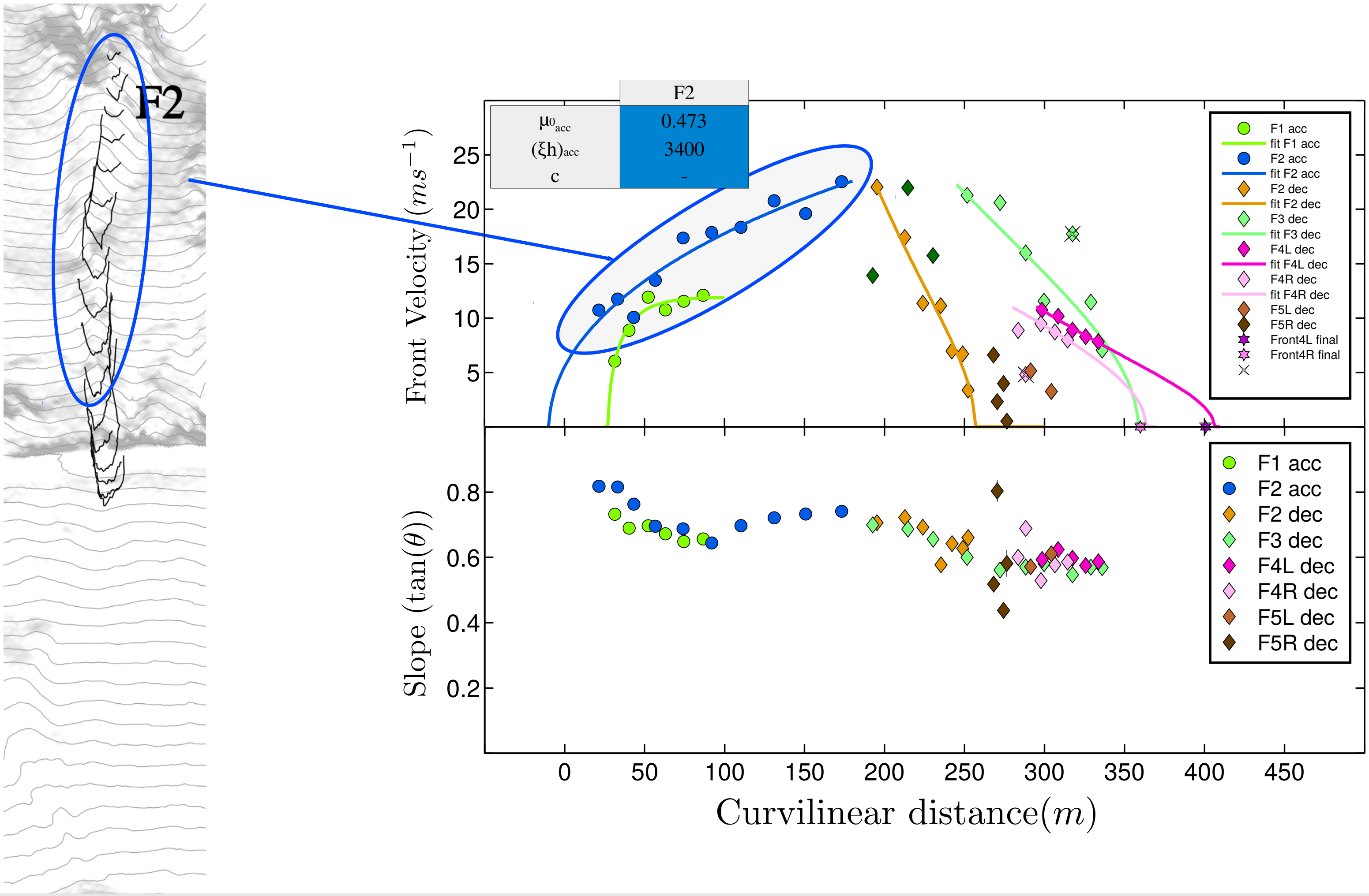
Sliding parameter : December 19th 2012



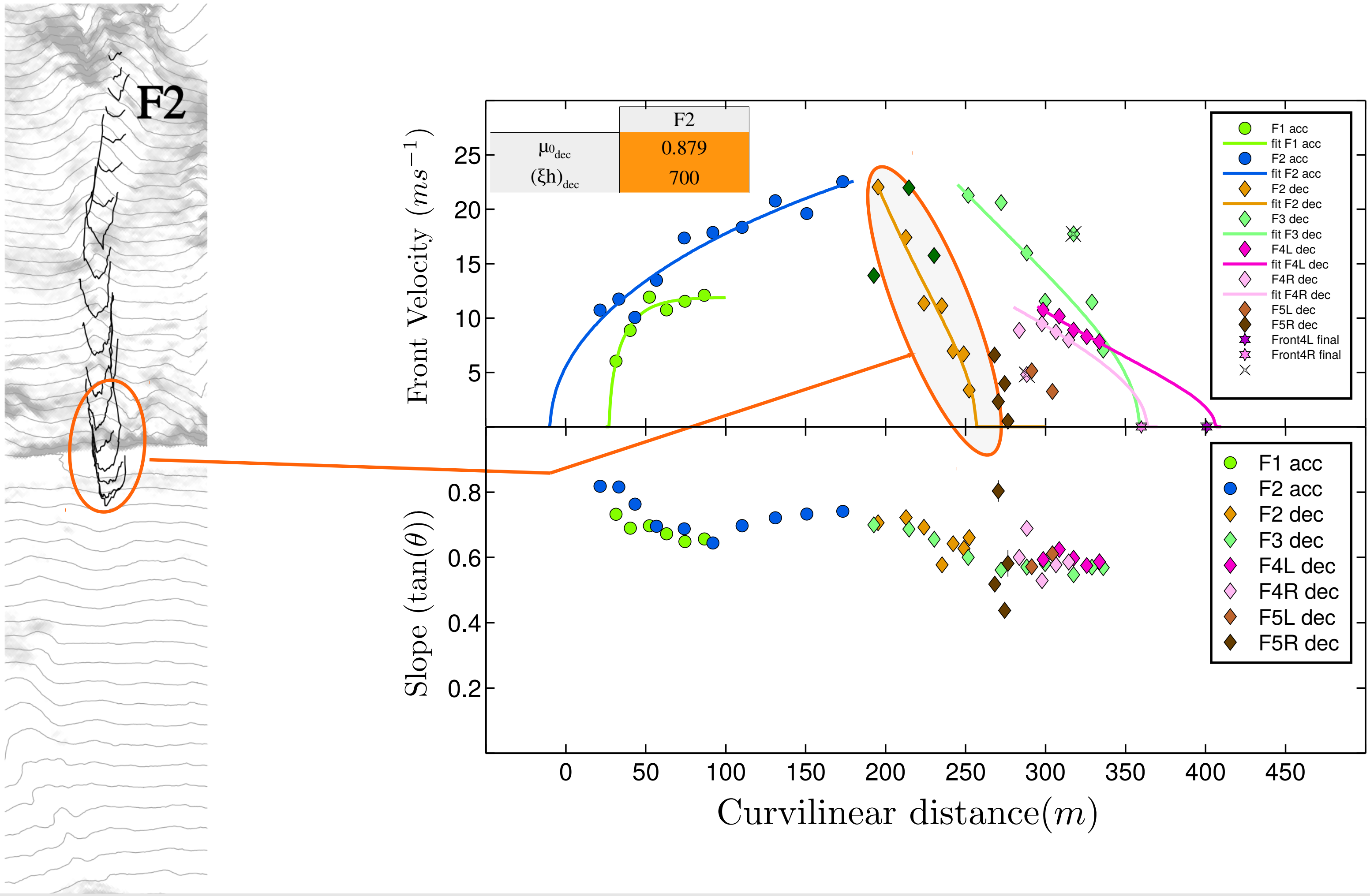
Sliding parameter : February 13th 2013



Sliding parameter : February 13th 2013



Sliding parameter : February 13th 2013



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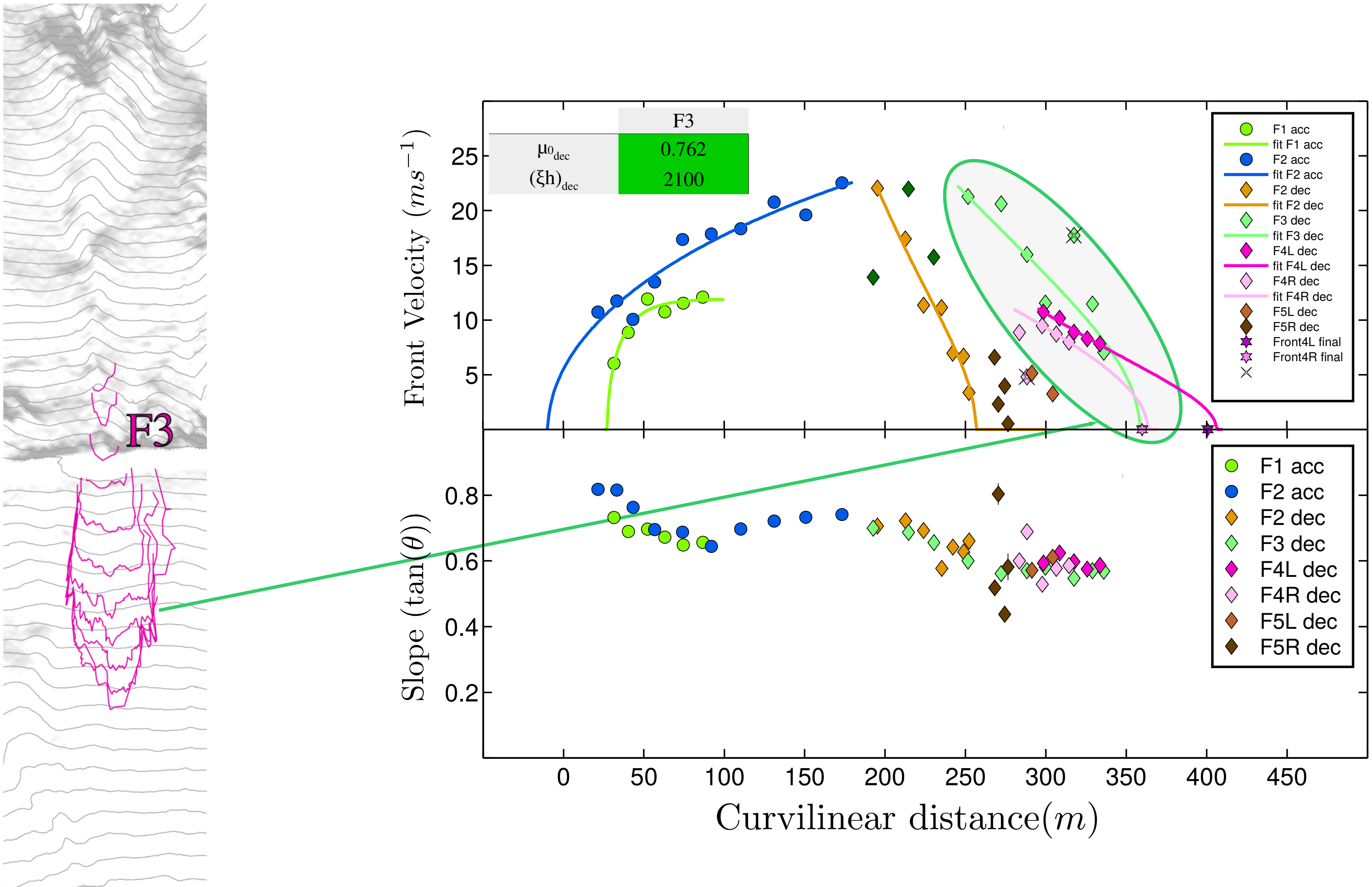
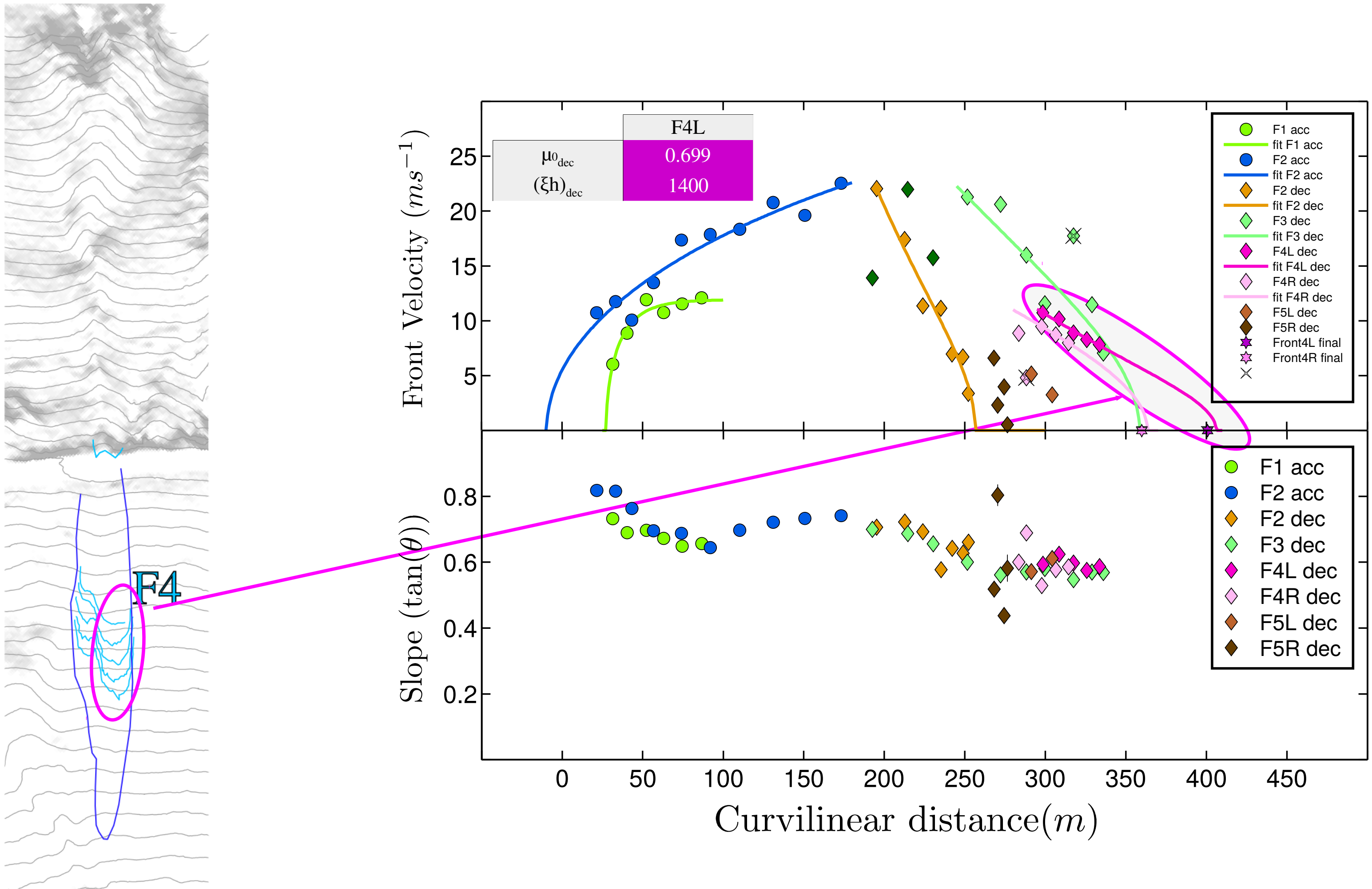
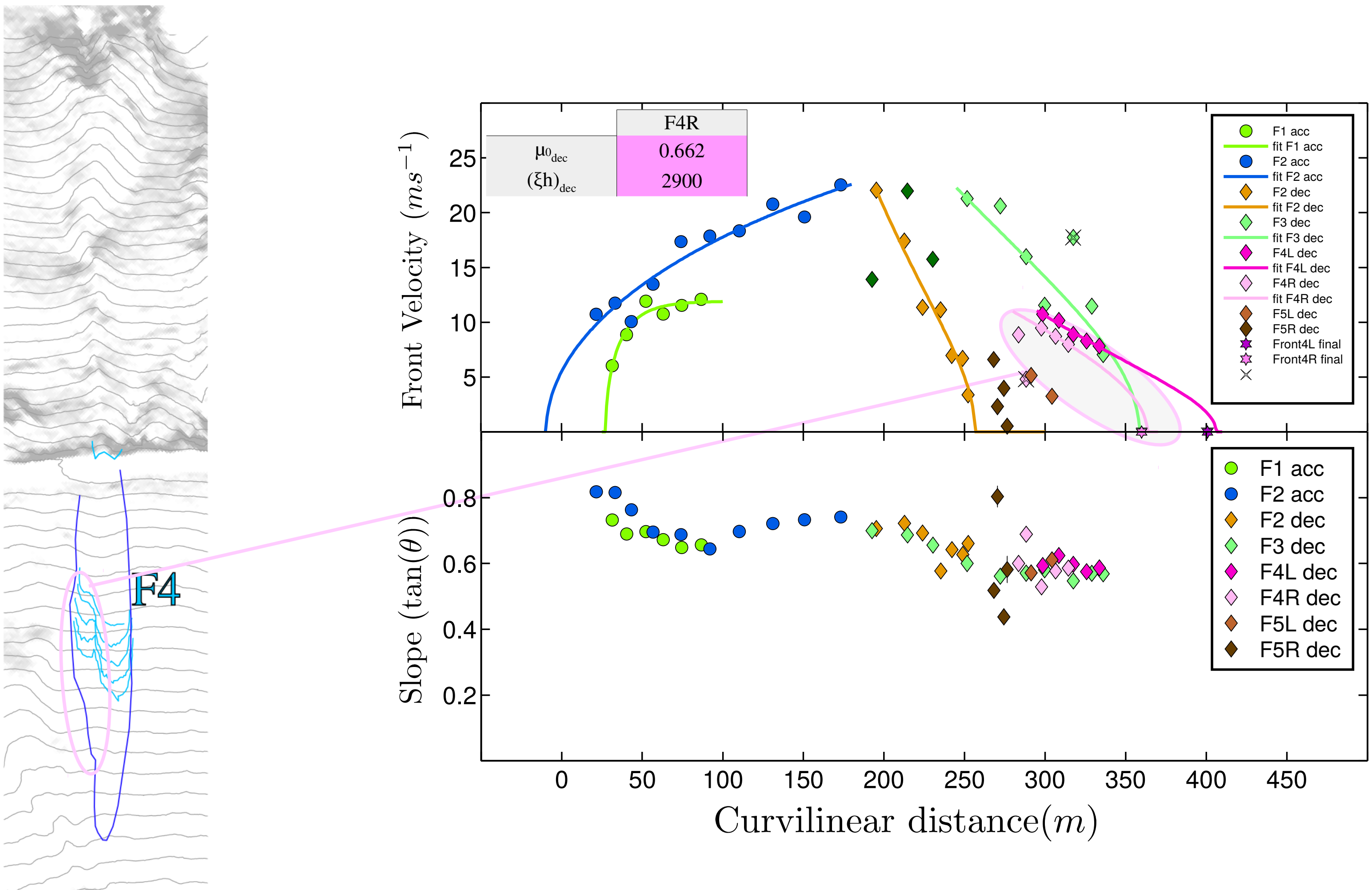
Sliding parameter : February 13th 2013



Sliding parameter : February 13th 2013



Sliding parameter : February 13th 2013



Result

Table of result with the value of the parameter obtain from the data fit and the value of the parameter.

For the accelerate area we got a value of μ_0 = 0.4-0.5. Except for the small surges where the value obtain are not really coherent.

For the run out μ_0 = 0.7-0.8 And the value is approximately constant for the different events.

The ξh value are similar for the different avalanches. It is difficult to have a good estimation on the parameter ξ because we don't know the thickness h. We know that h is under 1m. So the given value is a maximum estimation for ξ.

Accelerated flow

Date		$\langle\theta\rangle$ (°)	α	β	μ_{0acc}	$(\xi h)_{acc}$	c
2010/03/02	F1	34.7	14.0	0.0226	0.417	700	-35.09
	F1 (fit2)	34.7	20.0	0.0061	0.542	2600	-43.6
2012/12/19	F1	34.4	17.9	0.0116	0.455	1400	32.87
	F2	36.0	25.8	0.0084	0.374	1900	25.59
	F3	37.4	13.6	0.0671	-0.036	200	17.83
2013/02/13	F1	34.3	11.9	0.0720	0.051	200	27.44
	F2	36.1	29.37	0.004726	0.473	3400	-

Decelerated flow

Date		$\langle\theta_{dec}\rangle$ (°)	v_e	c_e	γ	δ	μ_{0dec}	$(\xi h)_{dec}$
2010/03/02	F1	30.4	16.3	225	390	0.0099	0.815	1700
2013/02/13	F2	33.4	22.05	195	154	0.0233	0.879	700
	F3	31.1	21.3	252	330	0.0081	0.762	2100
	F4L	30.8	10.7	299	141	0.0125	0.699	1400
	F4R	30.7	9.5	298	192	0.0059	0.662	2900

The classical value of the parameter are (Salm et al. 1990):

→ μ_0 = 0.25-0.3 for the small avalanches.

→ ξ = 1000m/s^2 for the area with uniform slope.

The value obtain from this study are bigger maybe because the avalanche observe are small (Volume<1000m^3).

Conclusion

In our study we develop an accurate and reliable system to measure the front velocity :

→ Give the 3D position of the front for different surges and during all the duration of the flow.

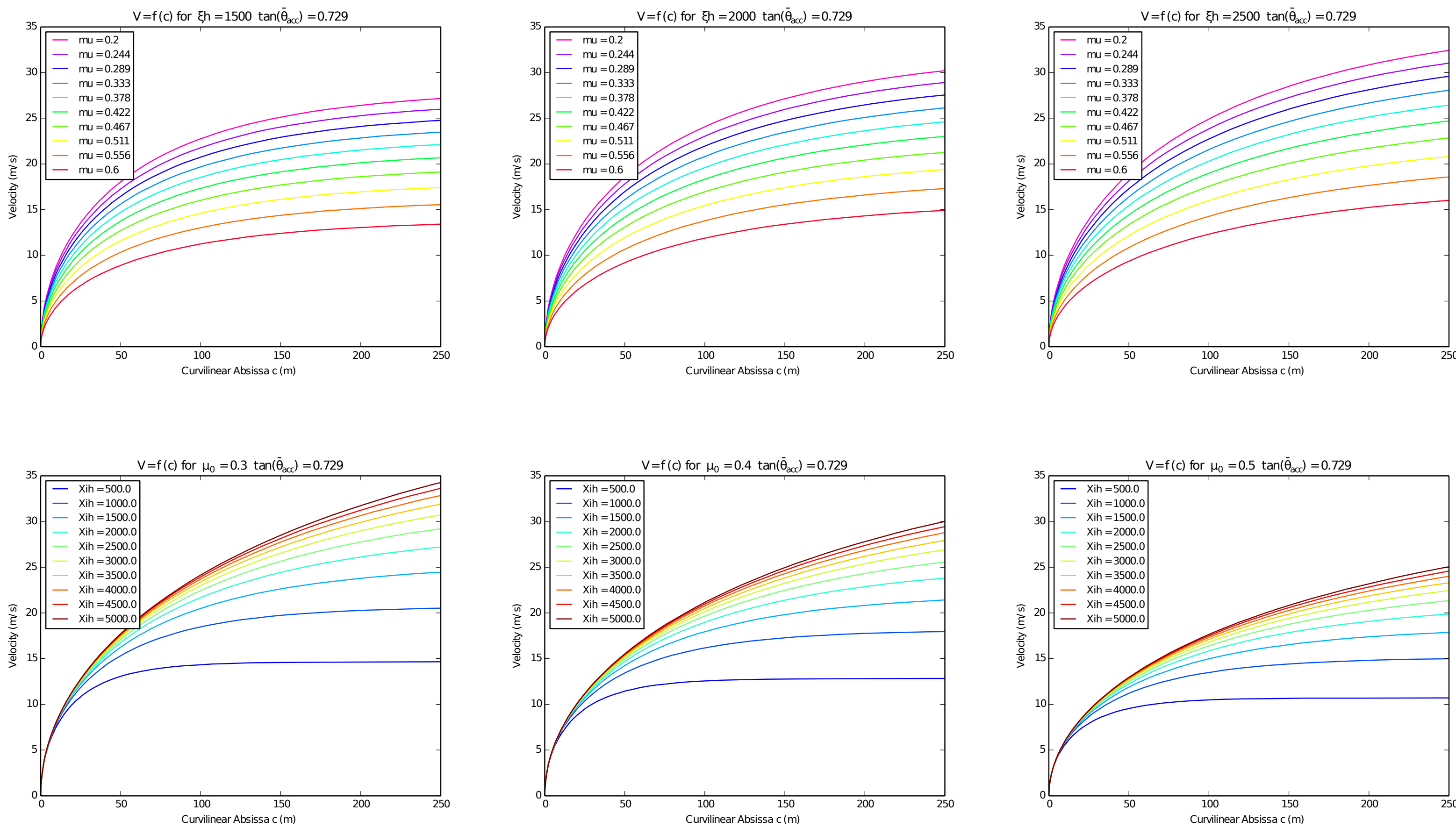
The analytical sliding block model: Give an estimation of the Voelmy's friction law parameter. For 5 different flow in the accelerate part and 5 flow for the run out area.

Give an input for the numerical model calibrate on dynamics data (not only run out distance).

Thank you for your attention.

Sensitivity study

Accelerated part of the flow:



Sensitivity study

Decelerated part of the flow: