TSX InSAR Assessment for slope instabilities monitoring in alpine periglacial environment
(western Swiss Alps)

C. Barboux, R. Delaloye, C. Collet

University of Fribourg, Switzerland

T. Strozzi

Gamma Remote Sensing AG, Bern, Switzerland

H. Raetzo

Federal Office for the Environment, Wabern, Switzerland

Fribourg Alpine Cryosphere and Geomorphology

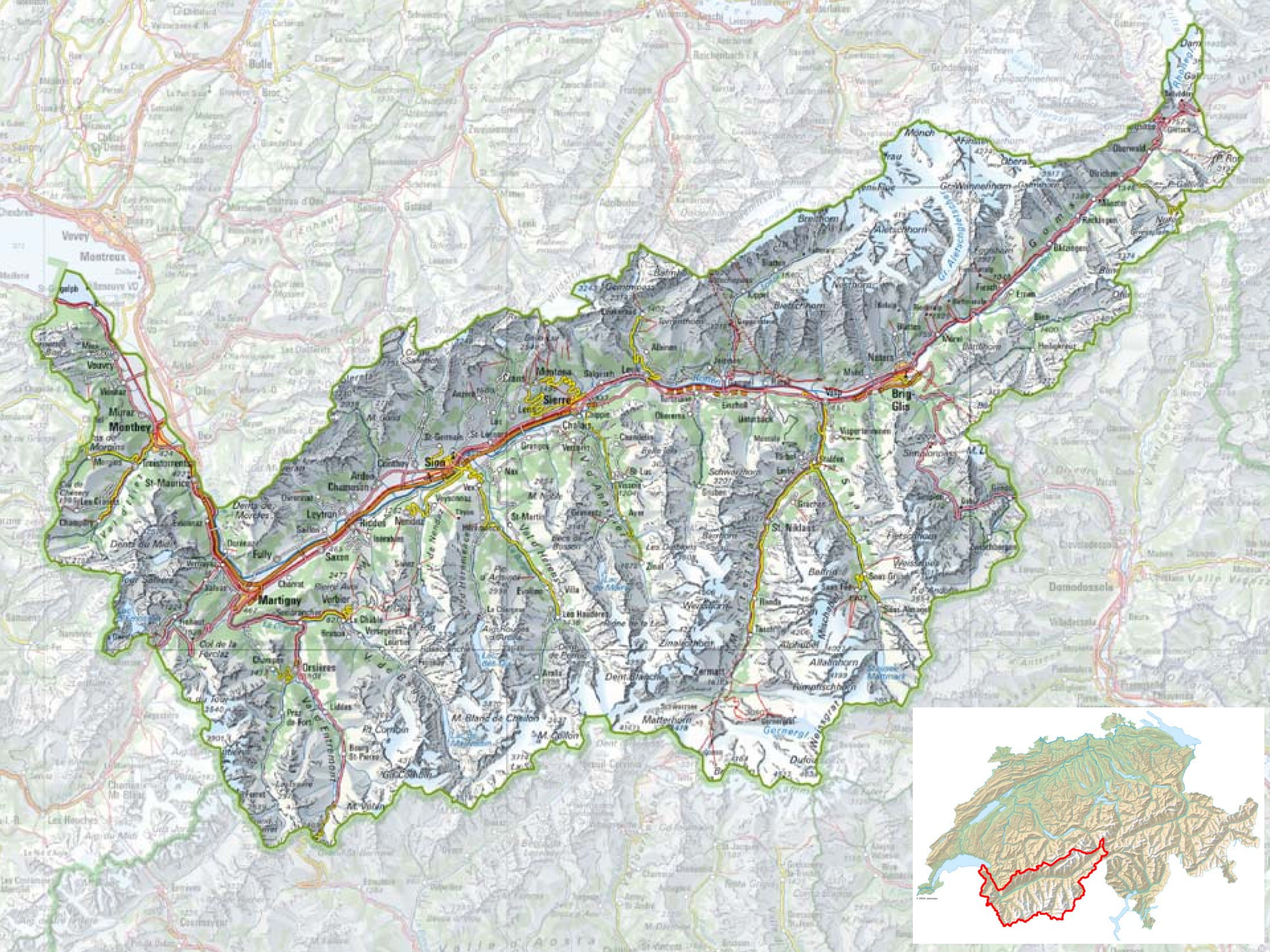
Universitas Friburgensis

Faculty of Science

Gamma Remote Sensing

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

19-23 September 2011 | ESA-ESRIN | Frascati (Rome), Italy



Vevey
Montreux
Bulle
Gstaad
Monthey
St-Maurice
Martigny
Fully
Saxon
Leytron
Chamoson
Ardon
Sion
Sierre
Montana
Crans
Leuk
Visp
Brig-
Glis
Naters
Zermatt
Matterhorn
St. Niklaus
Saas Fee
Verbier
Orsières
Domodossola
Gornergl.
Dufour
Zinalrothorn
Weisshorn
Aletschhorn
Fiesch
Münster
Oberwald
Le Châble
Champéry
Vouvry
Troistorrents
Col de la Forclaz
M. Blanc de Cheilon
Val d'Entremont
Valle d'Aosta

Introduction

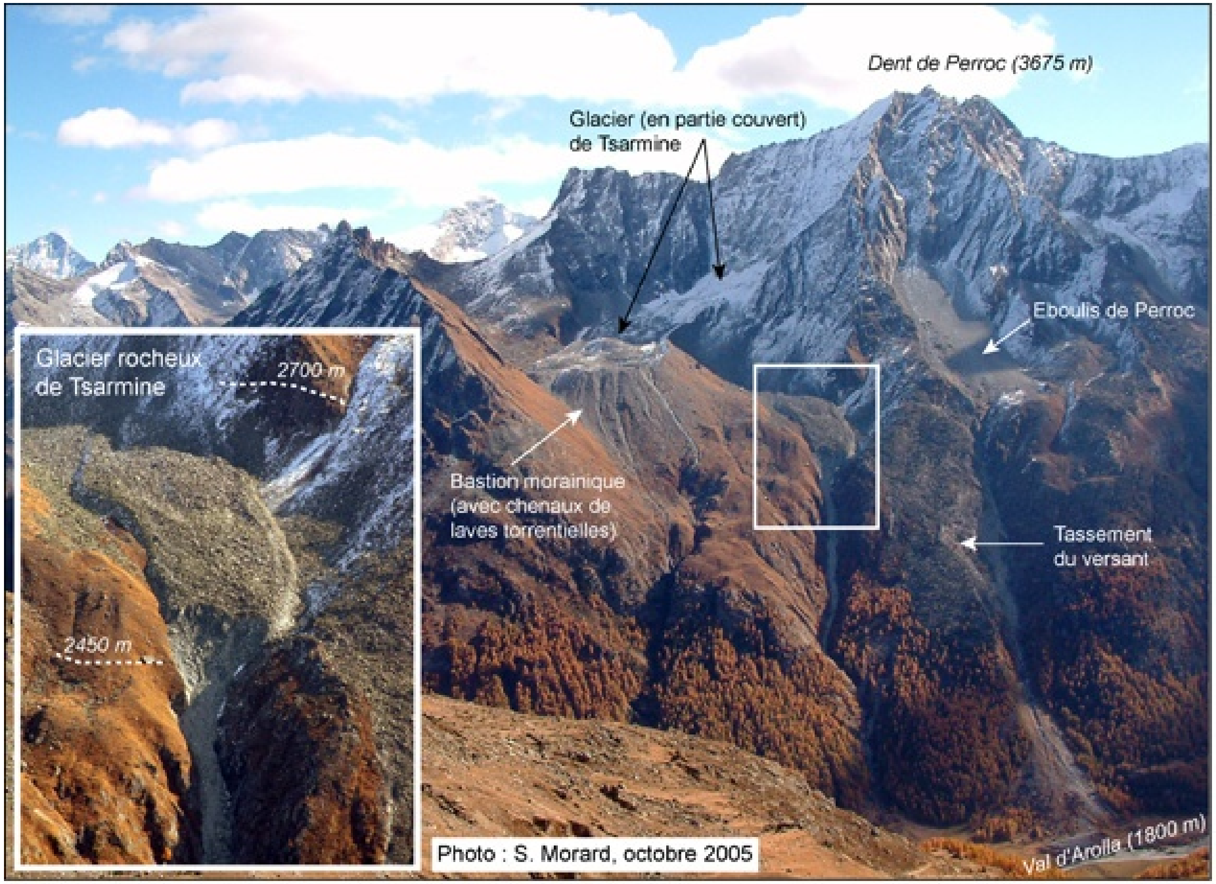
- **Periglacial environment** : alpine and high alpine zone potentially concerned by **permafrost**

- In the Valais Alps : **lower limit of permafrost** = 2400 m a.s.l. in northern exposition and 2700 m a.s.l. in south-facing slope

- **Periglacial belt**: portion located above this lower limit to the summits excluding glaciated area

Introduction

This environment is potentially affected by loose sediments



Introduction

- Perennially frozen terrain are **susceptible to move** and their dynamics are partly **controlled by the thermal state of permafrost**

- Any change in permafrost creep rate **modifies the transfert rate** of loose material along the alpine slope and **may affect the frequency, magnitude and type** of related slope instabilities

Introduction

Succeptible to move : permafrost creep

Introduction

- In the context of **climate change** and in view of **natural hazard risk management** in moutain region areas there is a great need to investigate **automated techniques** to **detect** and **monitor** slope instabilities

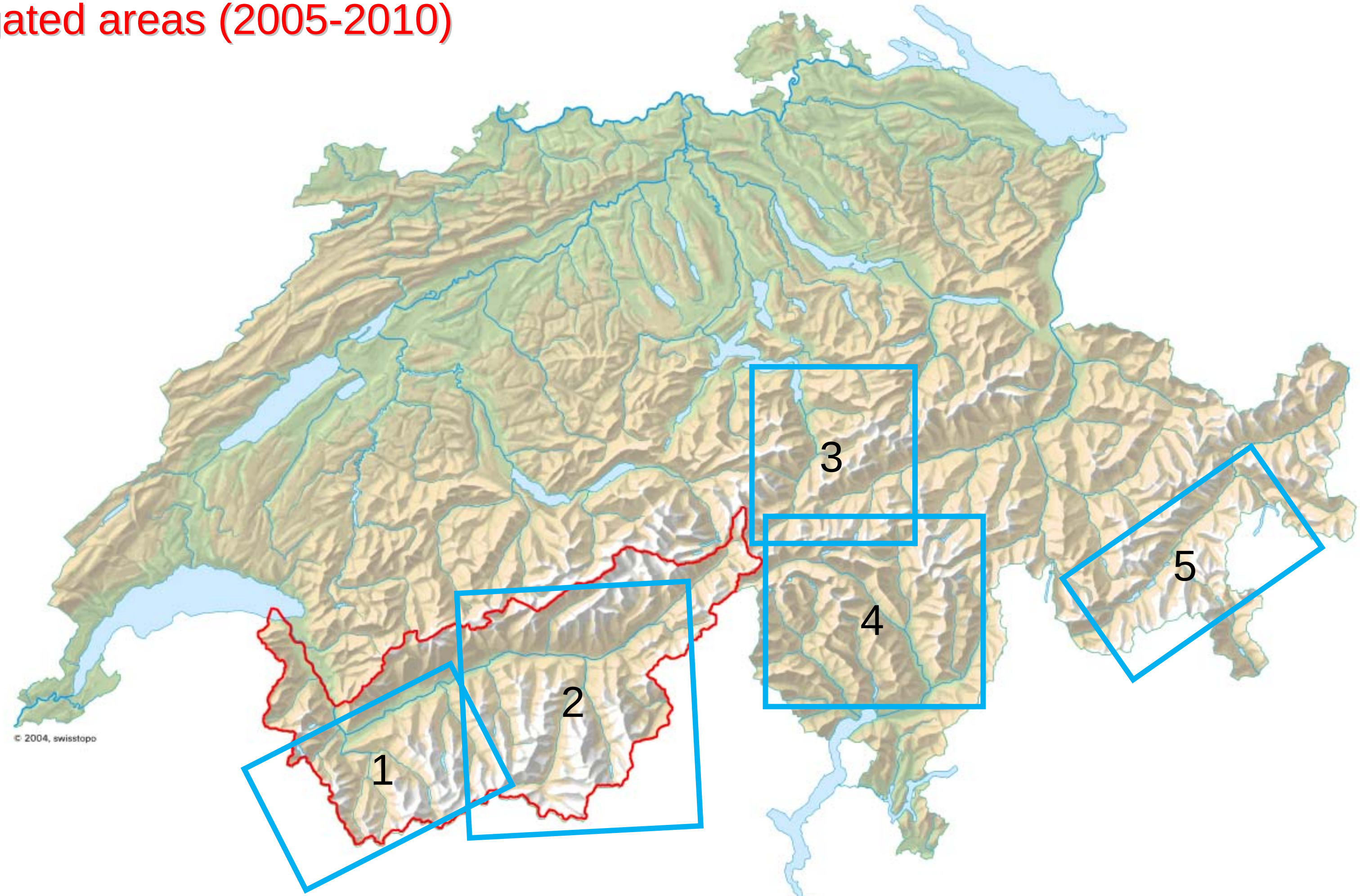
Studied area and InSAR

- The topography of the Western Swiss Alps, mainly consisting of **north-south oriented valleys** is **optimal** for an InSAR application

- Since 2005, several inventories of InSAR detected slope have been compiled at a **regional scale** using **large set** of InSAR data

Inventories of slope movement

Investigated areas (2005-2010)



Using available set of mainly ERS, ENVISAT, JERS, ALOS, etc. InSAR data from 1991 to 2000

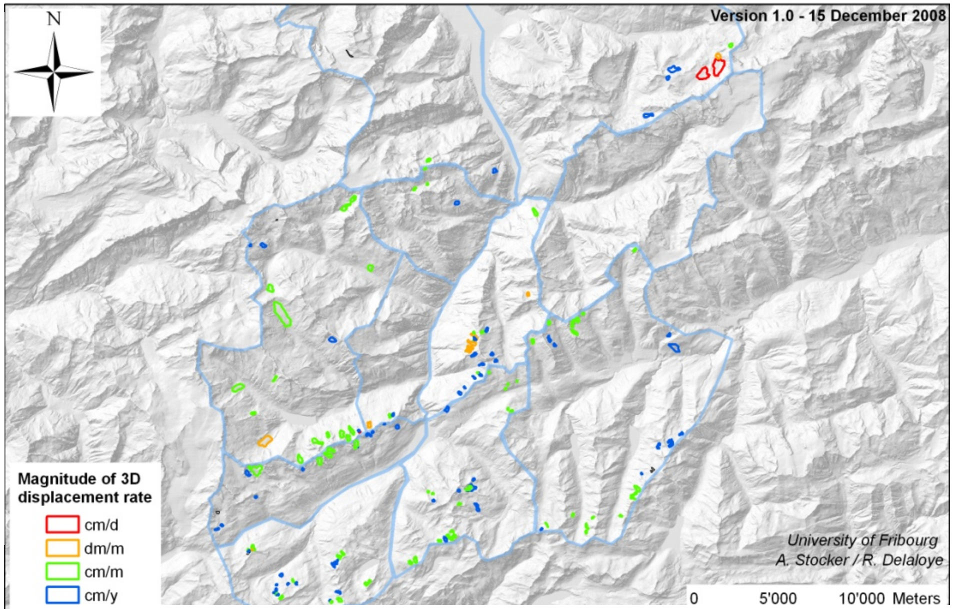
Inventories

About 2‘000 landforms outlined :

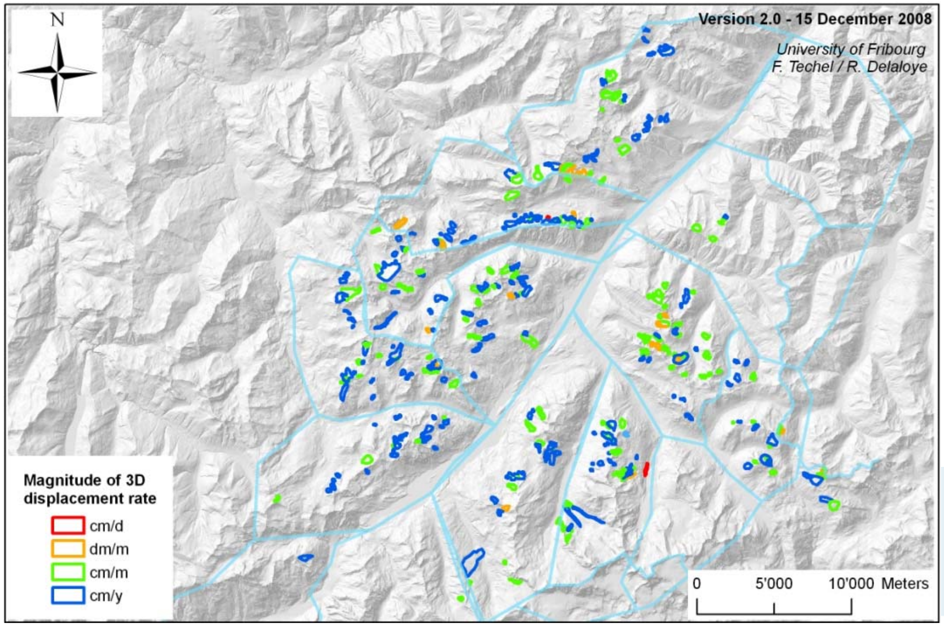
-Rock glaciers
-Debris-covered glaciers
-Landslides
-…

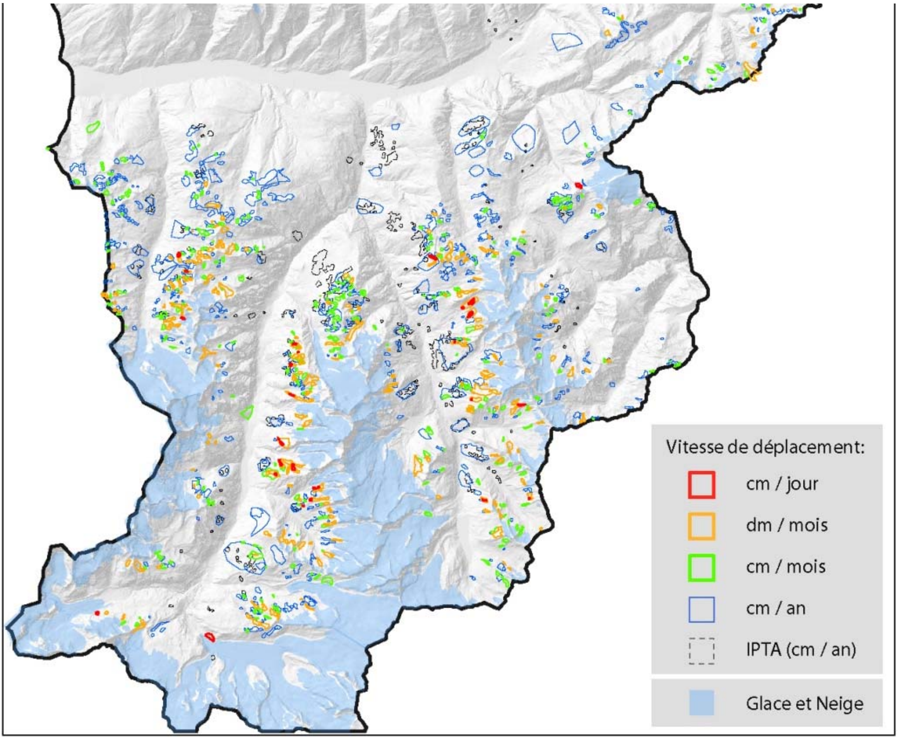
+ determination of the magnitude order of the displacement rate (cm/d, dm/m, cm/m, cm/y)

GOTTHARD-Nord / InSAR Analysis 1993-2007 / ERS1-2, JERS, ENVISAT, ALOS



BERNINA / InSAR Analysis 1993-2007 / ERS1-2, JERS, ENVISAT, ALOS





InSAR potential

- The use of InSAR **has been evaluated** to estimate magnitude of the movement and **verified** on different selected sites with known phenomena
- Fast moving slopes were detected thanks to **1- and 3-day** repeated cycle of ERS-1/2
- However **since the extinction** of ERS-1/2 tandem the higher rate of rapidly moving rockglaciers (>1m/y) **can no longer be detected or surveyed** on C-band and L-band monthly interferograms

Terrasar X potential

- Aim target : **investigate the potential** of TSX InSAR for slope motion monitoring in Valais

  Is these high resolution X-band interferograms with 11 days time interval are suitable for monitoring very active landforms ?

Terrasar-X InSAR Assessment

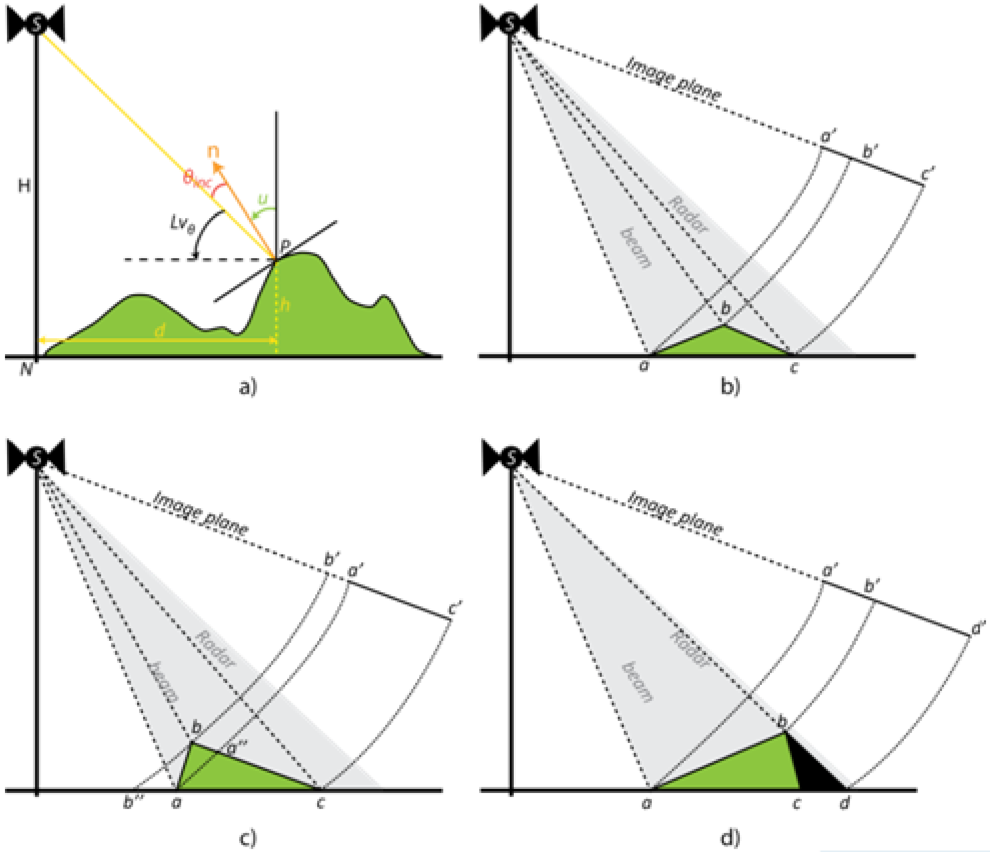
- In order to provide a **reliable assessment** of InSAR visibility for slope motion monitoring, a **map of visibility** characterizing the velocity compression is calculated.
- An index value ranging between 0 and 1 is used to determine the suitability of TSX to monitor each of our 30 surveyed test-landforms.

Terrasar-X InSAR Assessment

- ***1st step*** : Exclude areas which are polluted by **irreversible** geometric distorsions

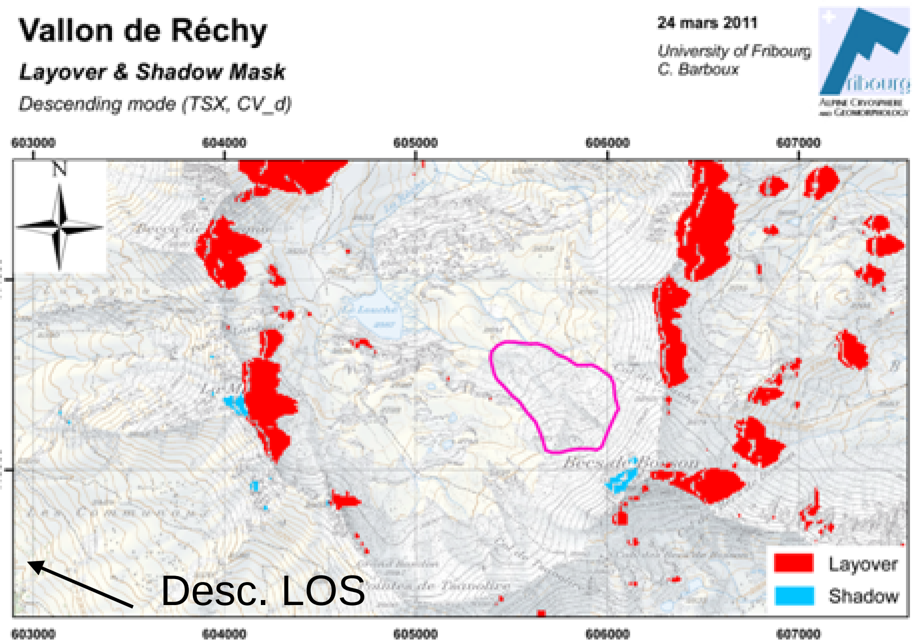
Visibility mask

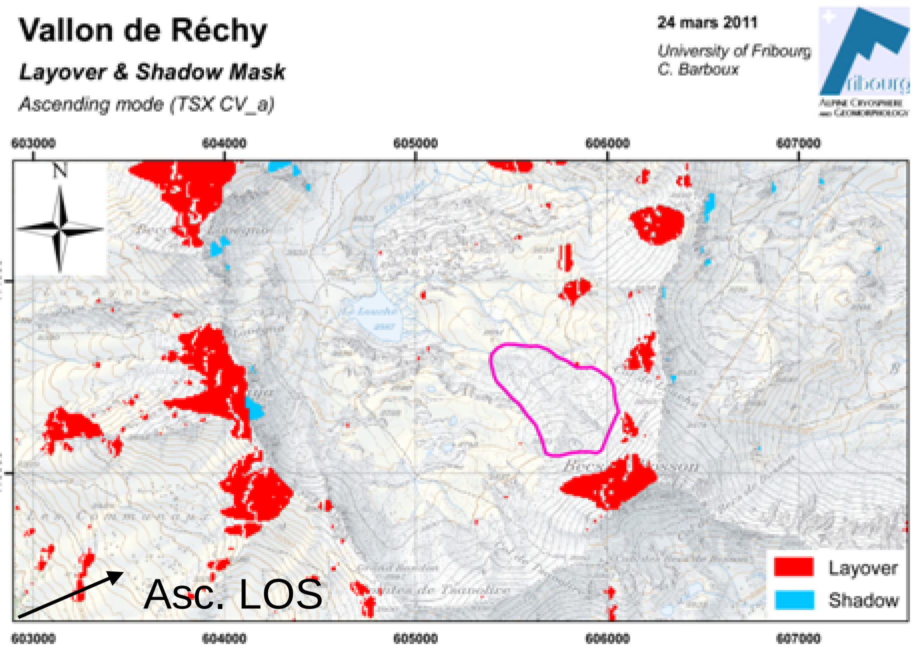
- Objective : exclude layover and shadow



Visibility mask

- Typical results





- Limitations : binary characterization of InSAR visibility

Terrasar-X InSAR Visibility

- ***1st step*** : Exclude areas which are polluted by irreversible geometric distorsions

- ***2nd step*** : Determine a **quality index**, ranging between 0 and 1, which characterizes the InSAR visibility. The quality of the observation is evaluated for the displacement on a unit area of the ground surface which is directly related to the topography and the look angle.

Visibility map

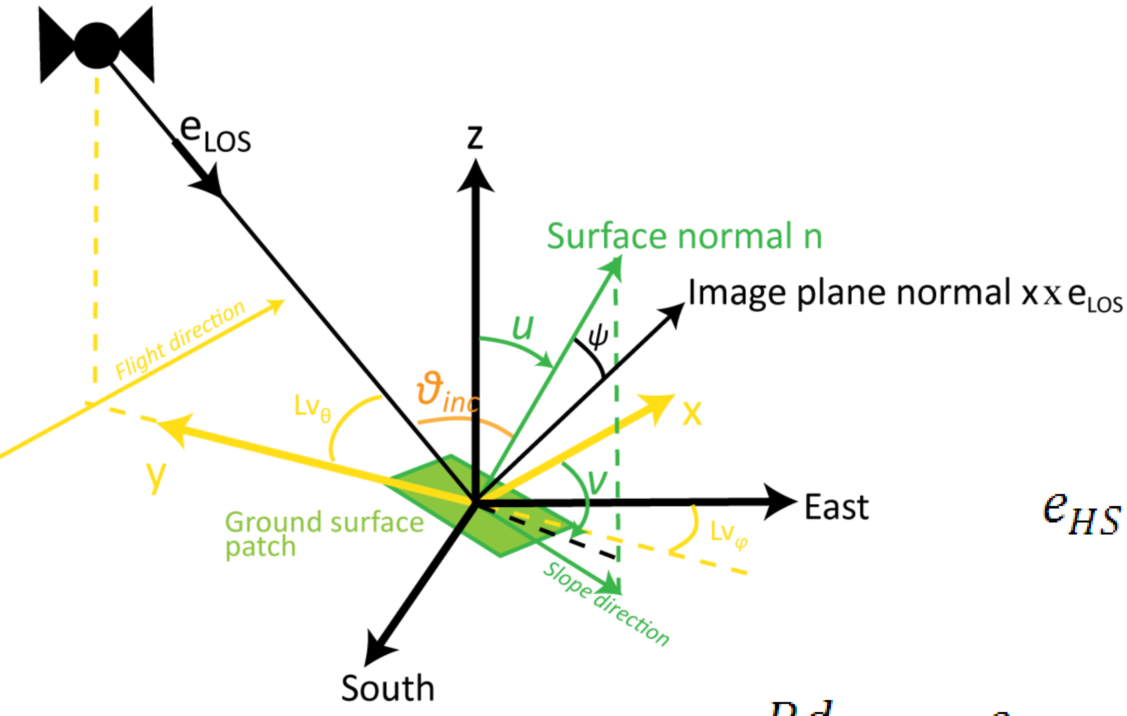
- Hypothesis : the flow v_{HS} is directed down slope everywhere

$$v_{HS} = \frac{v_{LOS}}{e_{LOS} \cdot e_{HS}} \qquad Rd_{HS} = e_{LOS} \cdot e_{HS}$$

- where :
  - $v_{LOS.}$: displacement projected in the LOS direction.
  - e_{LOS} : unit vector of the displacement in the LOS direction
  - e_{HS} : unit vector of the flow in the highest slope direction
  - *RdHS* : velocity compression

Visibility map

- RdHS calculation :



$$e_{Los} = \begin{cases} \cos(Lv_\theta)\cdot\cos(Lv_\varphi) \\ \cos(Lv_\theta)\cdot\sin(Lv_\varphi) \\ \sin(Lv_\theta) \end{cases}$$

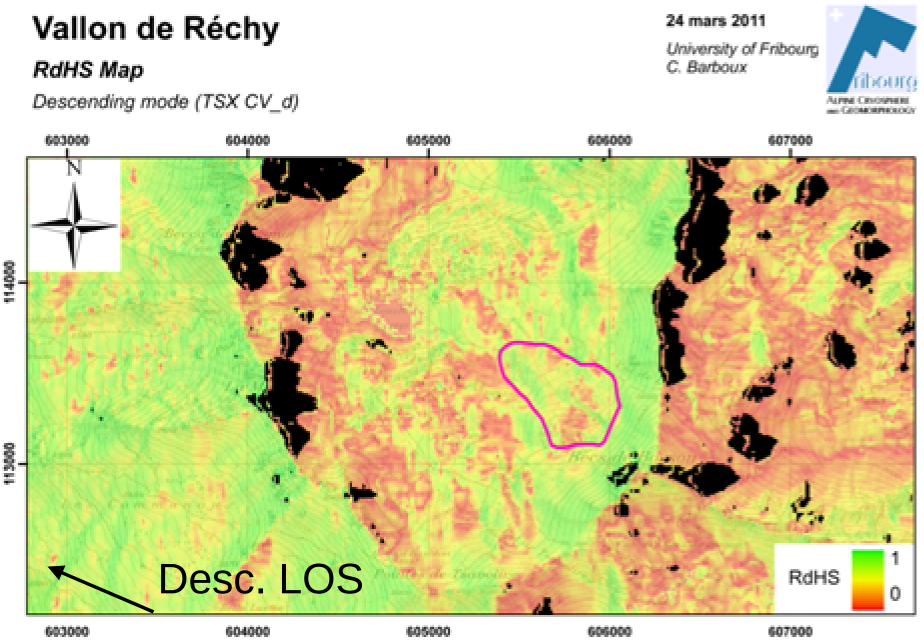
$$e_{HS} = \begin{cases} \cos(u).\cos\left(v-\frac{\pi}{2}+Lv_\varphi\right) \\ \cos(u).\sin\left(v-\frac{\pi}{2}+Lv_\varphi\right) \\ -\sin(u) \end{cases}$$

$$Rd_{HS} = e_{LOS}\cdot e_{HS}$$

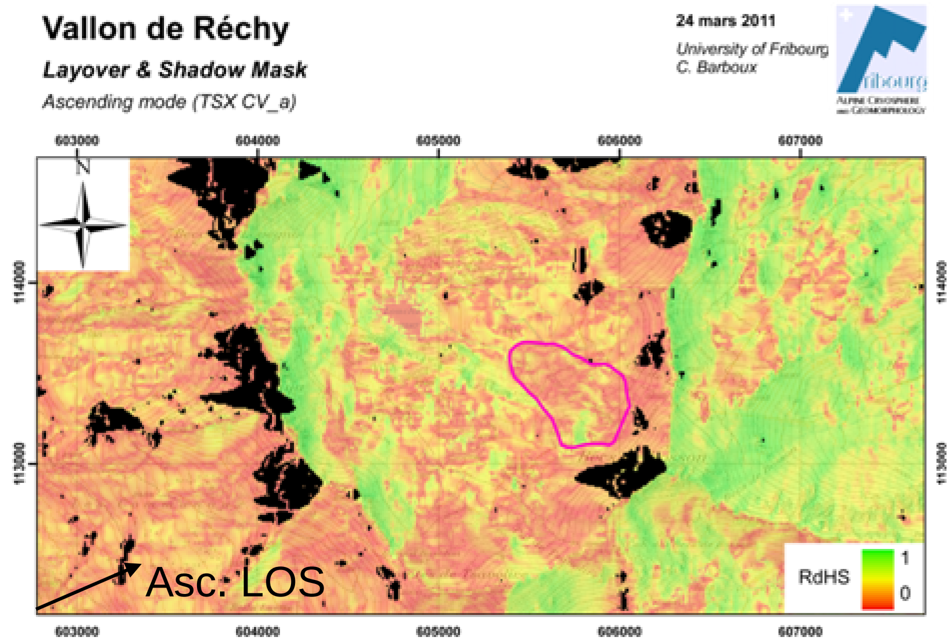
$$Rd_{HS} = e_{LOS|x}.e_{HS|x} + e_{LOS|y}.e_{HS|y} + e_{LOS|z}.e_{HS|z}$$

Visibility map calculation

- Typical results



Descending : RdHS = 45% (std = 0.21)



Ascending RdHS = 77% (std = 0.14)

UNIVERSITAS FRIBURGENSIS

DEPARTMENT OF GEOSCIENCES

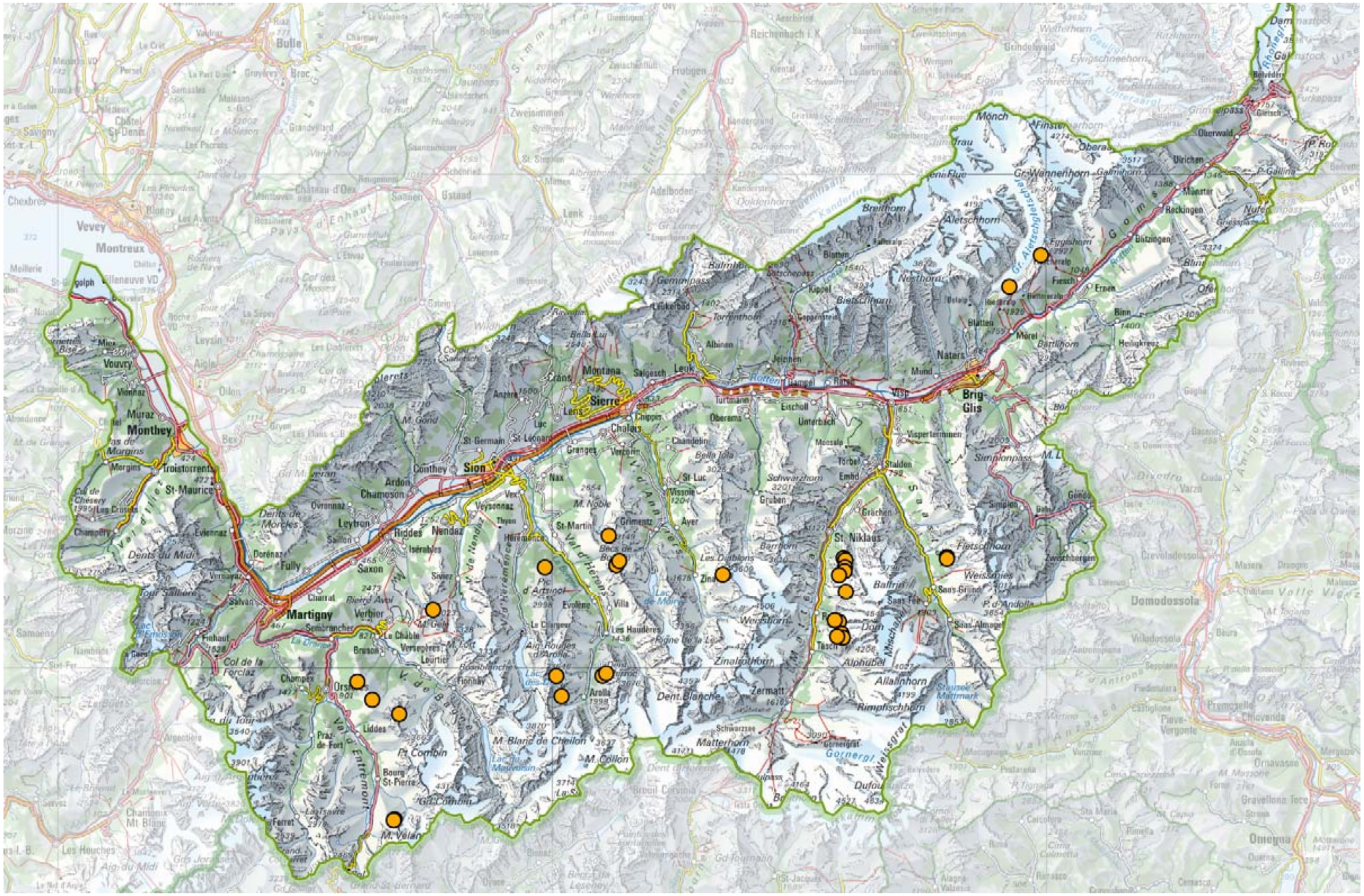
geography

Application to the Valais

- **85.6%** of the alpine periglacial belt is **visible by TSX** InSAR. Remaining area is either masked by layover or shadow or not covered by the specific orbits.

- **Almost 49.2%** of the belt is visible in both two modes

30 surveyed landforms



30 landforms are annually or seasonally surveyed by GPS field measurements since 2000 for the longest series

UNIVERSITAS FRIBURGENSIS

DEPARTMENT OF GEOSCIENCES

geography

30 surveyed landforms

- **Different kind of typology** : 18 rock glaciers, 9 landslides, 2 covered glaciers and 1 moraine
- Most of them are located on slope of about 25° and have an area smaller than 10ha. Their flows are more or less 11.6° directed toward the highest slope direction
- **97,1% of these landforms are visible** by TSX either in ascending or in descending mode. Remaining area is in layover or shadow

InSAR Visibility calculation

- When the visibility score does not exceed 50%, the specified mode is turned down for the considered landform.
  - 21 landforms can be observed in 2 modes, 9 in only one mode

- The visibility map was computed for each landform

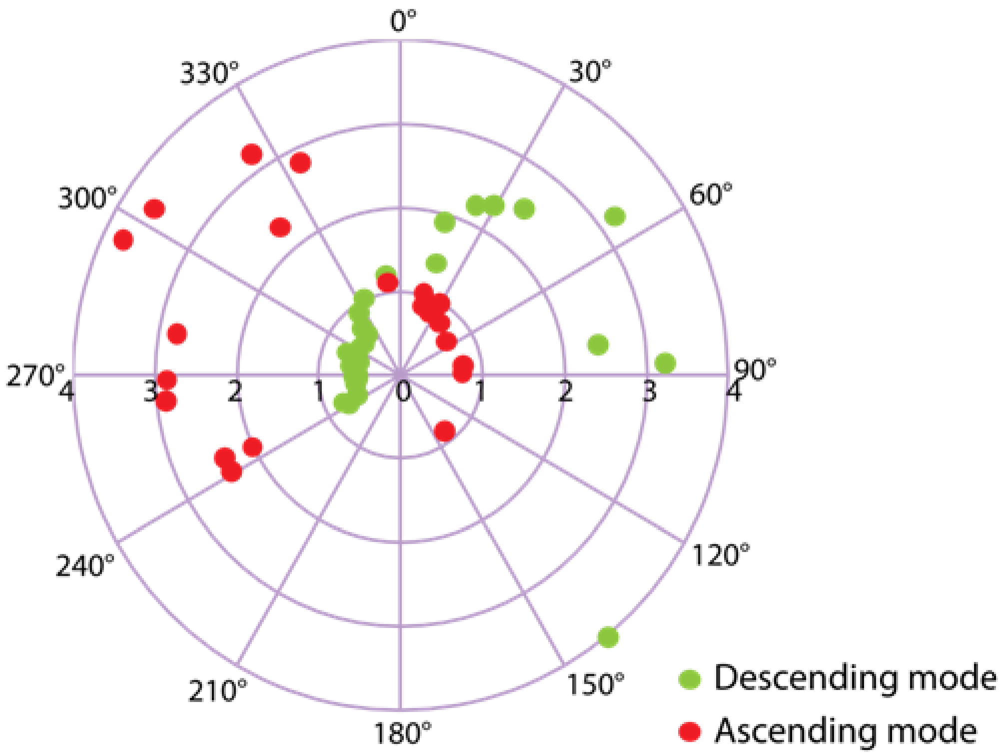
- Then the maximal deformation rate was computed

$$V_{\max} = \frac{v_{LOS|\max}}{R_{dHS}} = \frac{0.51}{R_{dHS}} [m/y]$$

with $v_{LOS|max} = \lambda/2$

InSAR Visibility calculation

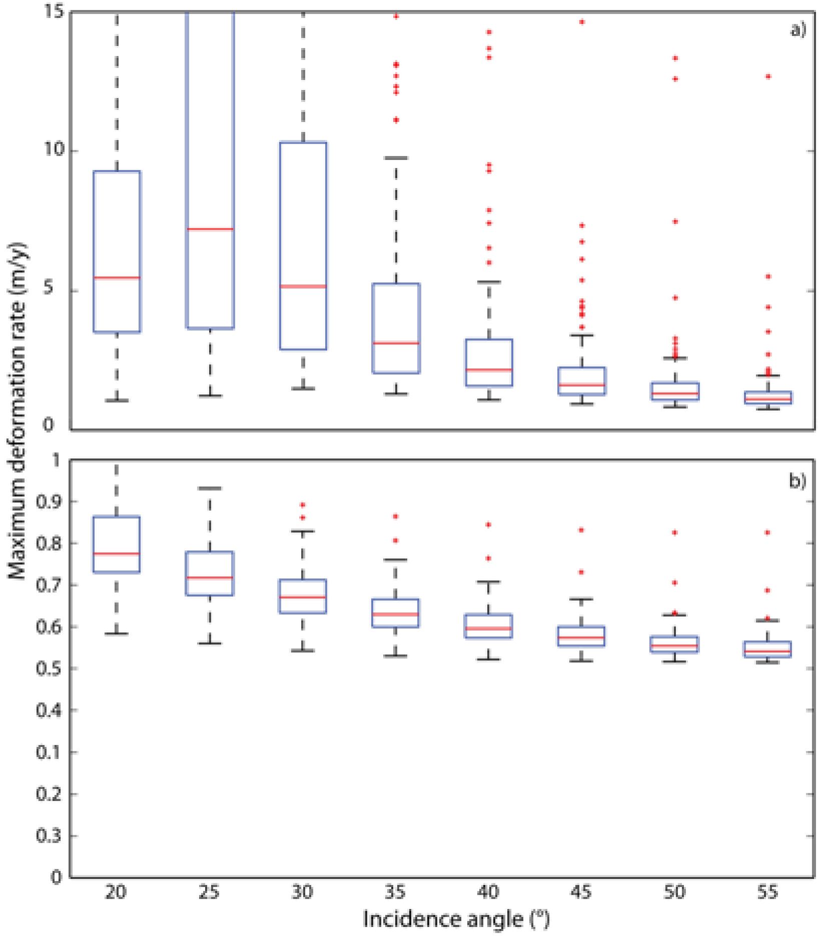
Maximum detectable deformation rate (m/y) for testing sites according to their aspect



- For most of the west-oriented landforms *Vmax* can reach 1m/y in descending mode and 3.5 m/y in ascending mode
- Reverse phenomena for east-oriented landforms
- *Vmax* reaches 1m/y in both modes for north-oriented landforms

UNIVERSITAS FRIBURGENSIS
DEPARTMENT OF GEOSCIENCES
geography

InSAR Visibility calculation



Influence of the incidence angle on *Vmax*
Typical result for the Tsarmine west-oriented rockglacier

- For most west-oriented landforms the incidence angle has few influences on *Vmax* which can reach 7 to 8 m/y
- However, large layover could occur on landform for this mode
- No influence in descending mode
- Reverse phenomena for east-oriented landforms

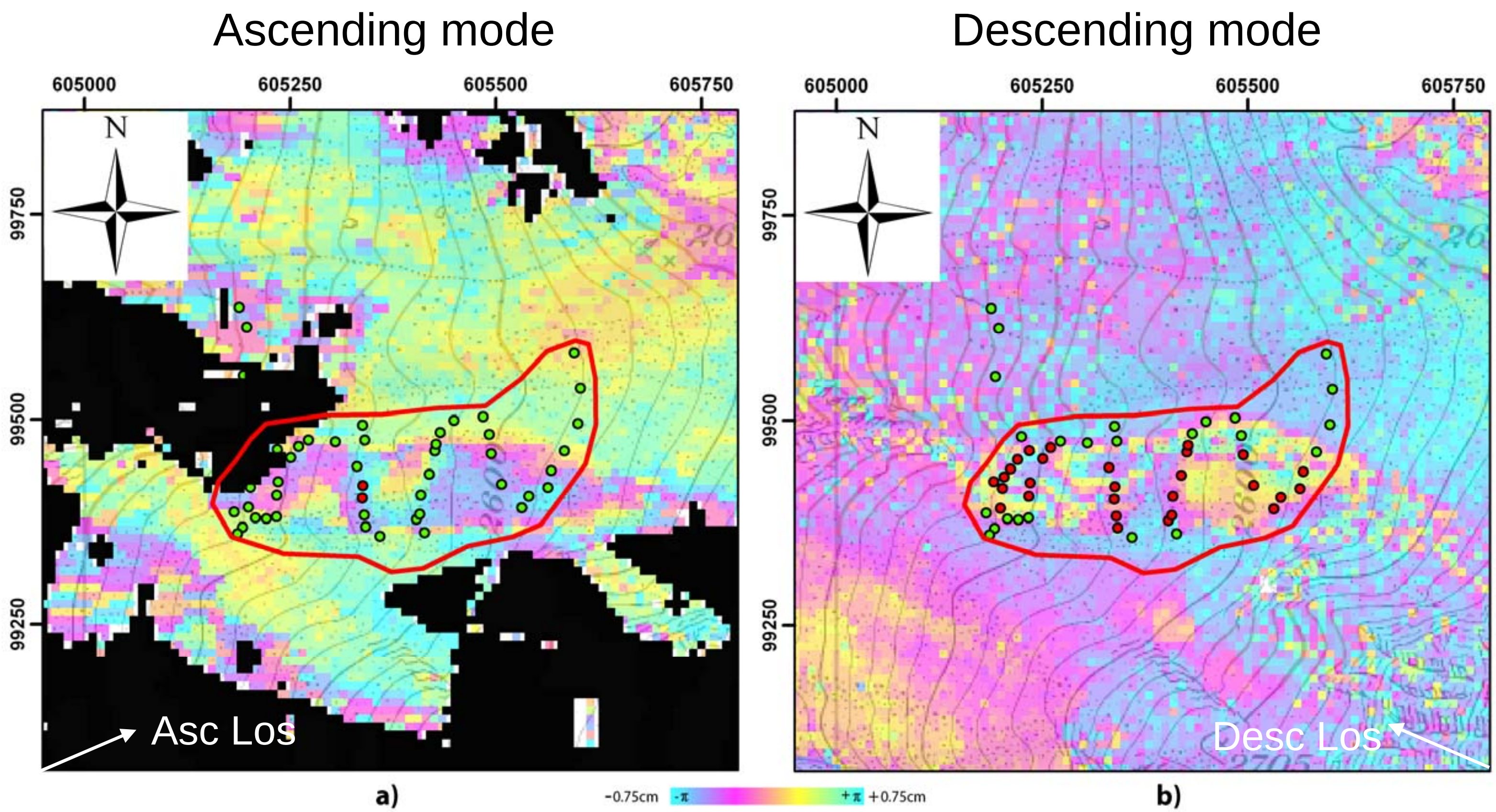
Discussion

- Some comparison were performed by combining InSAR observations and differential GPS measurements :

  The maximal deformation rate was compared to the local velocity, for each surveyed GPS point which is classified as detectable or undetectable

- In most cases, the detectable and undetectable point classification corresponds to InSAR observation (in term of correlated and decorrelated signal respectively).

Discussion



Localization of GPS points detectable by InSAR
superimposed with InSAR data from 2010 with an 11-day time lag
Green points are detectable with TSX InSAR;
the movement is too fast for any monitoring when points are red.

Conclusion

- It is possible to monitor some very active rockglaciers (1-3.5m.y^{-1}) when geometrical distortions do not hide them with the shortest repeat pass of 11 days.
- Lower velocity rates could be well monitored using longer time lags.
- At higher rate velocities, decorrelation occurs in most cases and TSX appears to be unsuitable for a precise analysis of these kinds of very rapidly moving landforms.
- The high resolution of TSX looks suitable to monitor slope instabilities with narrow width (until 50 meters width).

Thanks for your attention !

UNIVERSITAS FRIBURGENSIS

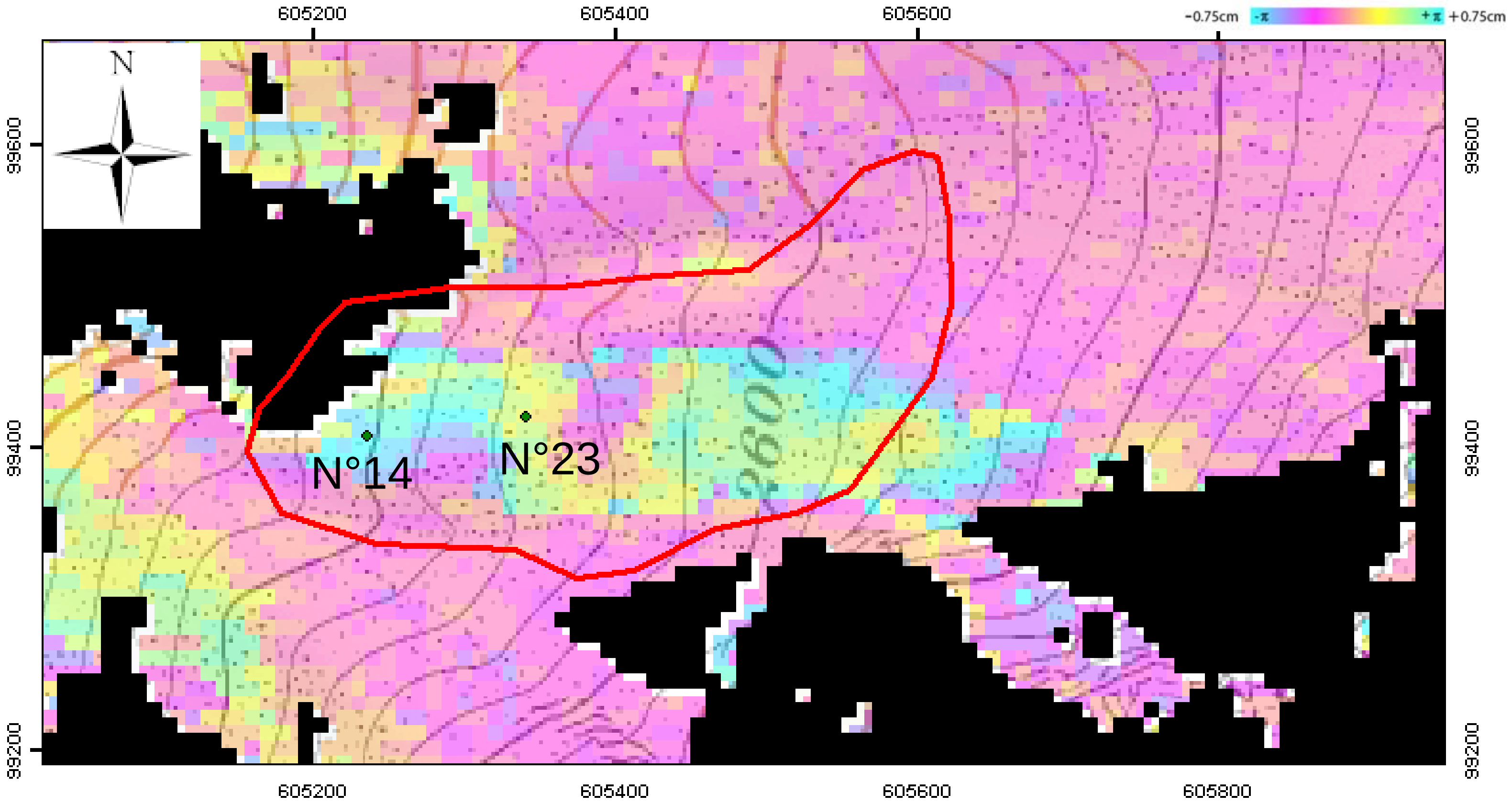
DEPARTMENT OF GEOSCIENCES

geography

Discussion

TSX Ascending : 11 days 20100718-20100729

RdHS =0.19



N° 14 : (0.3*1.5/0.19)*(365/11)= 79 cm/y; 84 cm/y (GPS 2010);

N° 23 : (0.8*1.5/0.19)*(365/11) = 210 cm/y; 214 cm/y (GPS 2010);

UNIVERSITAS FRIBURGENSIS
DEPARTMENT OF GEOSCIENCES