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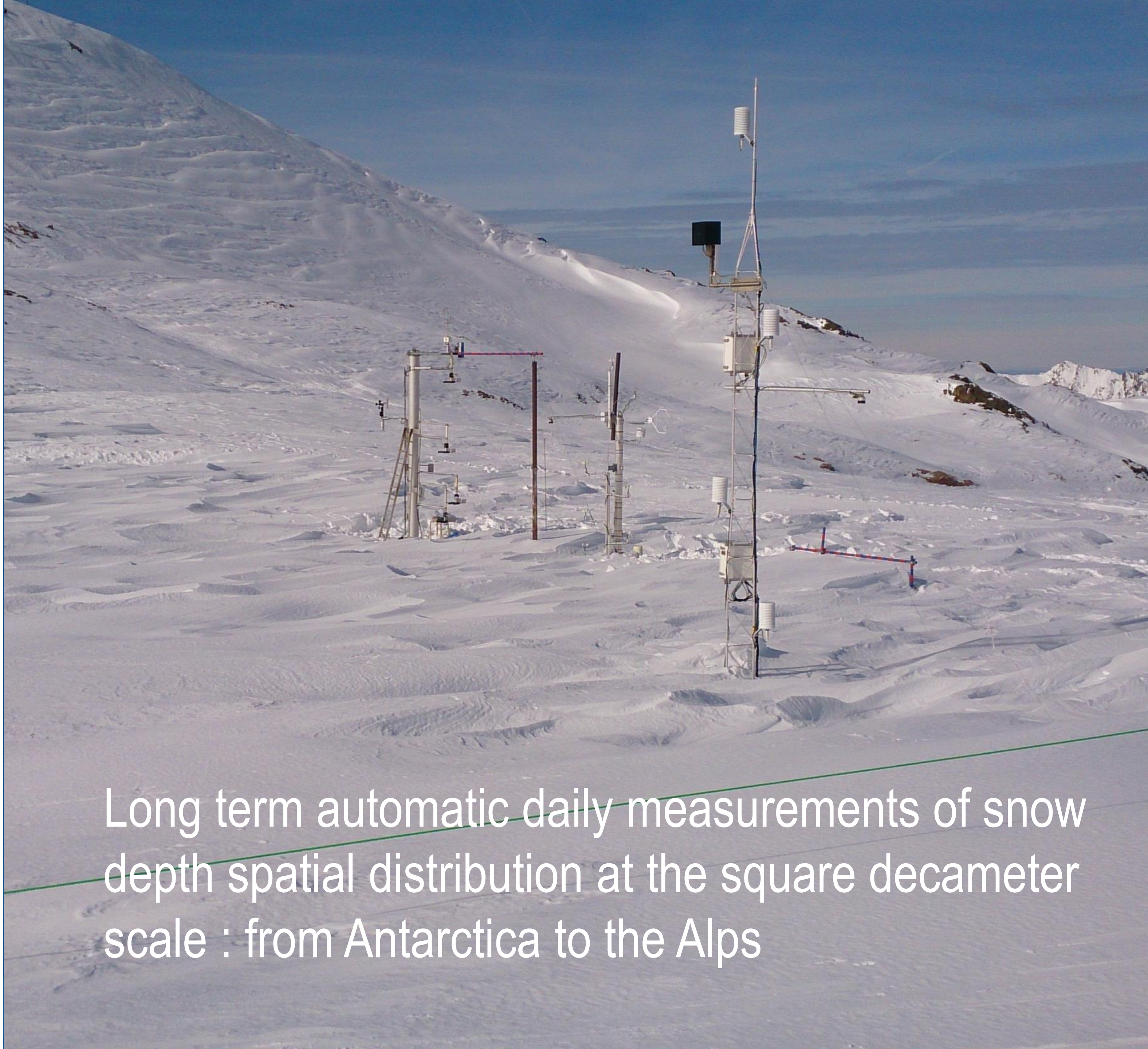
G. Guyomarc'h

Y. Deliot

METEO FRANCE

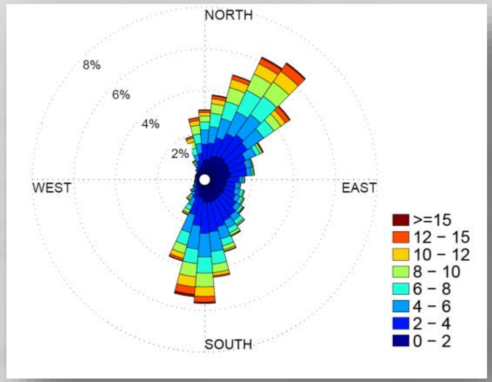


Long term automatic daily measurements of snow depth spatial distribution at the square decameter scale : from Antarctica to the Alps

1. Snow depth measurements in windy areas

> Lac Blanc Pass

- **Data collected from 1989**



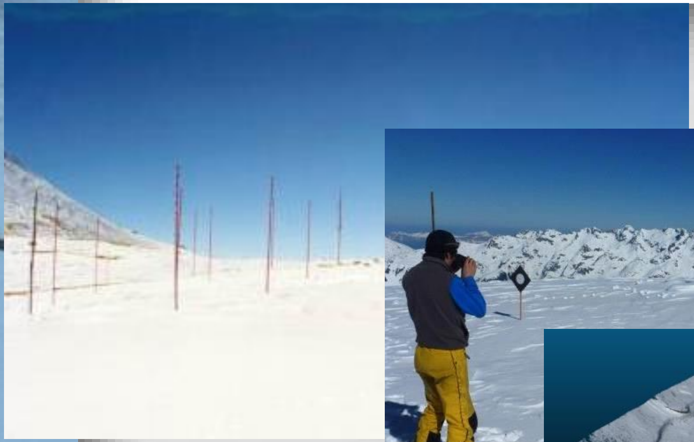
- Drifting snow : 10% of time during winter
- Drifting snow > 100 t/m²/year

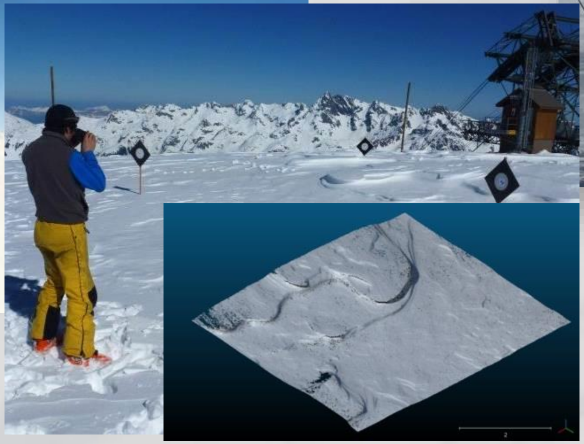
Vionnet, V., Guyomarc'h, G., Naaim Bouvet, F., Martin, E., Durand, Y., Bel, C., Bellot, H., Puglièse, P. 2013. Occurrence of blowing snow events at an alpine site over a 10-year period: observations and modeling, *Adv. Water Res.*, 55, 53-63.
Naaim Bouvet, F., Bellot, H., Naaim, M., Back analysis of drifting snow measurements over an instrumented mountainous site, *Annals of Glaciology*, International Glaciological Society, 2010, 51 (54), p. 207 - p. 217.

1. Snow depth measurements in windy areas

> Different snow depth sensors for different types of measurements

Snow depth (HS) - Stakes	**32**	53.3 %
Snow depth (HS) - Rulers	**22**	36.7 %
Snow depth (HS) - Snow probe	**19**	31.7 %
Snow depth (HS) - MagnaProbe	**3**	5 %
Snow depth (HS) - Ultrasonic and laser depth sensors	**34**	56.7 %
Snow depth (HS) - Time-lapse photography	**8**	13.3 %
Snow depth (HS) - Terrestrial and air-borne Laser Scanner	**12**	20 %
Snow depth (HS) - Unmanned Aerial Vehicle & Photogrammetry	**7**	11.7 %
Snow depth (HS) - Ground Penetrating Radar	**6**	10 %





Schon, P., Prokop, A., Vionnet, V., Guyomarc'h, G., Naaim Bouvet, F, 2015. Improving a terrain-based parameter for the assessment of snow depths with TLS data in the Col du Lac Blanc, Cold Region Science and Technology, 114, 15-26
Bellot, H., Naaim Bouvet, F., Ito, Y., Deschatres, M., Amory C., Characterization of sastrugi fields with TLS and simple digital photos, EGU 2014, Vienna.

1. Snow depth measurements in windy areas

> ….. among other sensors

Drifting snow occurrence - Visual observation	**12**	28.6 %
Number flux of drifting snow - Snow particle counter	**5**	11.9 %
Number flux of drifting snow - Mechanical trap & wind speed measurements	**3**	7.1 %
Number flux of drifting snow - Camera system with light source	**1**	2.4 %
Number flux of drifting snow - FlowCupt acoustic sensor	**8**	19 %
Number flux of drifting snow - Disdrometer	**4**	9.5 %

Trouvilliez, A., Naaim-Bouvet, F., Bellot, H., Genthon, C. and H. Gallée (2015) – "Evaluation of the FlowCapt acoustic sensor for the aeolian transport of snow, Journal of Atmospheric and Oceanic Technology", 32, 1630-1641.
Bellot, H., Trouvilliez, A., Naaim-Bouvet, F., Genthon, C., Gallée, H. - 2011. Present weather sensor tests for measuring drifting snow. Annals of Glaciology, vol. 52, n° 58, p. 176-184.

1. Snow depth measurements in windy areas

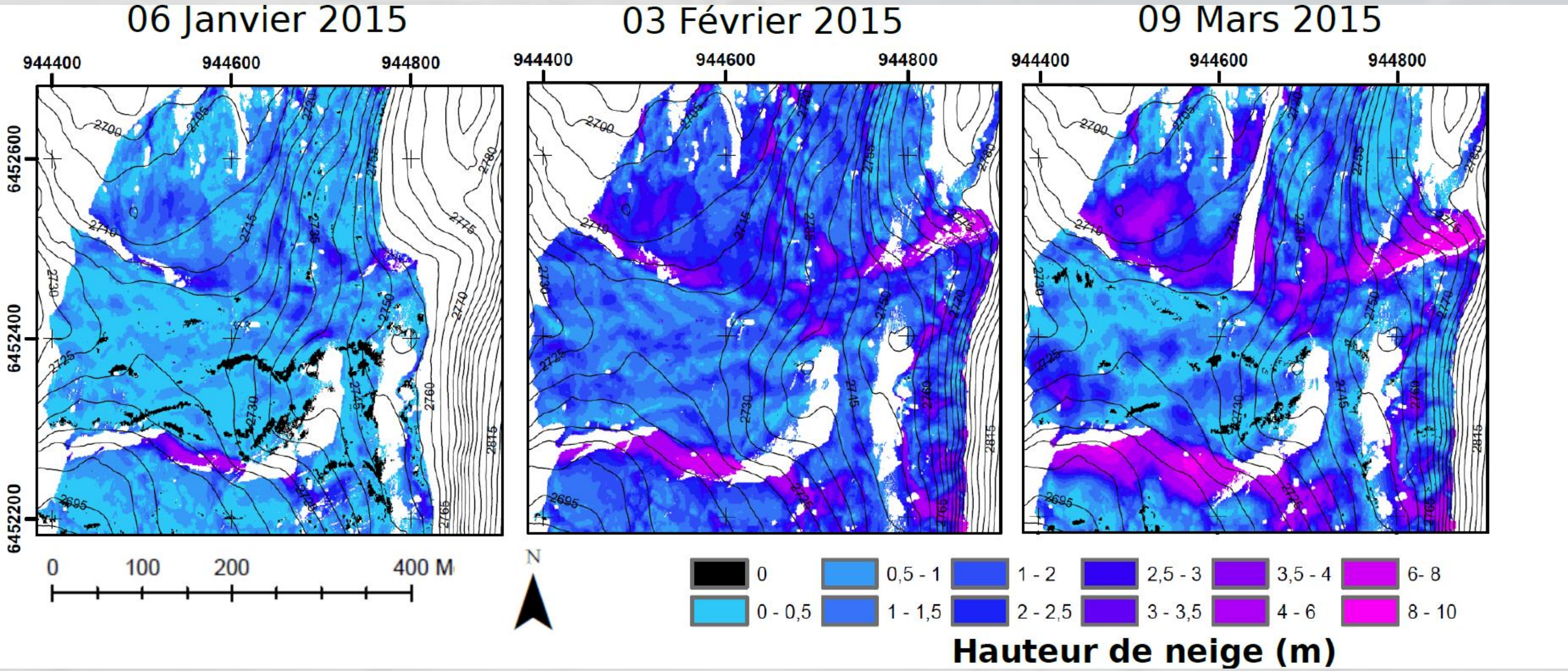
> ….. among other sensors

Snow roughness length (aerodynamic roughness) - Wind profile	4	6.7 %
Snow surface roughness - Laser scanner	8	13.3 %
Snow surface roughness - Photography	8	13.3 %

Naaim Bouvet, F., Bellot, H., Naaim, M., Back analysis of drifting snow measurements over an instrumented mountainous site, *Annals of Glaciology*, International Glaciological Society, 2010, 51 (54), p. 207 - p. 217.

1. Snow depth measurements in windy areas

> Influence of topography



- Raster : 1m*1m

Richard A., 2015, Suivi de l'enneigement saisonnier sur un site de haute altitude par balayage laser terrestre, Mémoire de diplôme d'Ingénieur INSA, Meteo France-Irstea

1. Snow depth measurements in windy areas

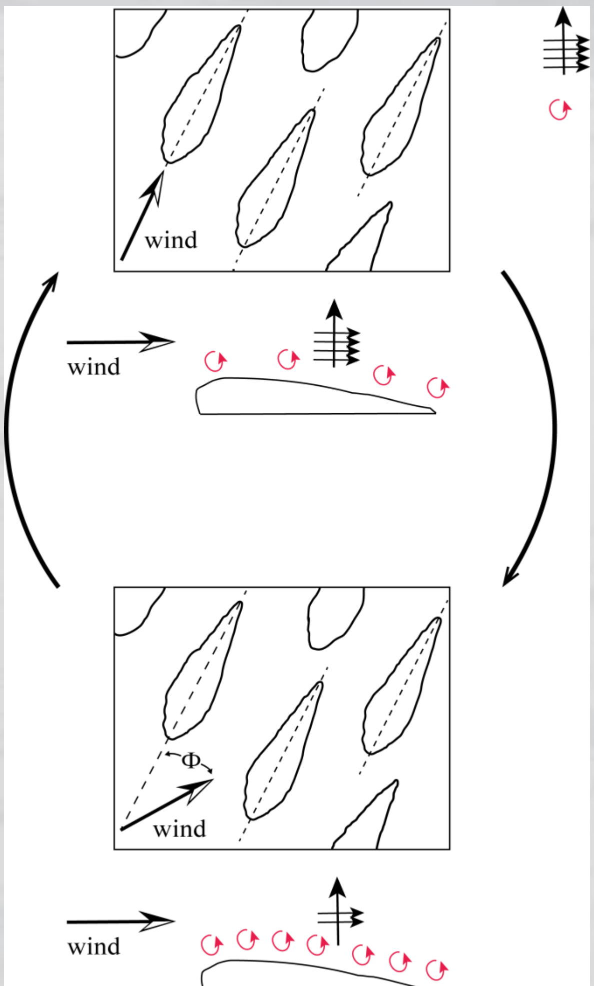
> Influence of topography - but not only --!

- Sastrugi : elongated metric-scale ridges of wind-packed snow whose longitudinal axis is parallel to the prevailing wind at the time of their formation

- Raster : 1m*1m is not enough

2. Focus on sastruggi

> Sastrugi aerodynamical adjustement



Drifting snow

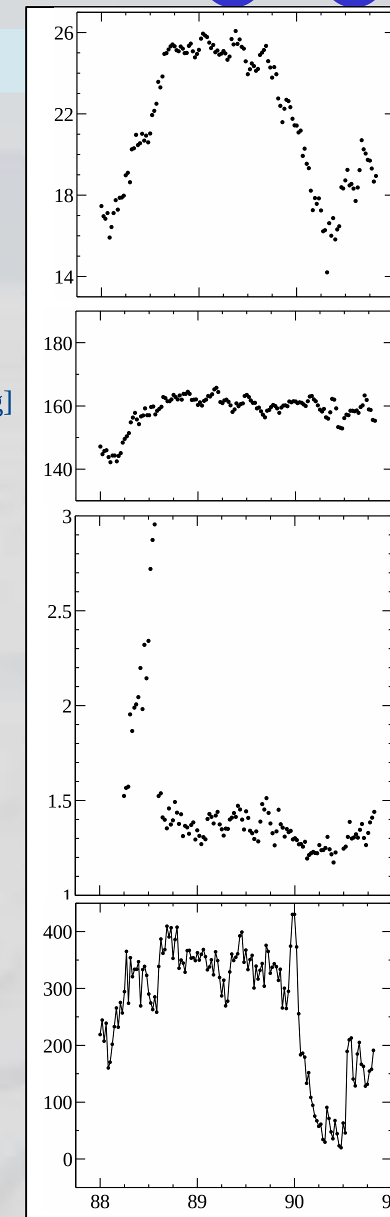
Loss of wind momentum

U_{2m} [m.s^{-1}]

Direction [deg]

10^3 C_{DN10}

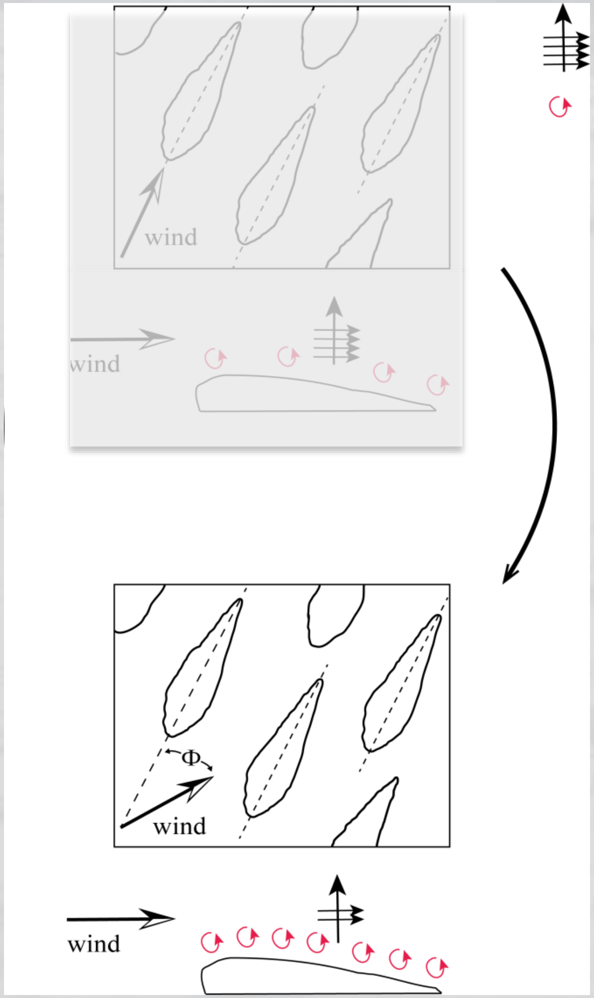
Horizontal drifting snow flux [g.m^{-2}.s^{-1}]



Amory C., Naaim-Bouvet F., Gallée H., Vignon E. (2015) – "Two cases of sastrugi aerodynamical adjustement" – *The Cryosphere Discussion.*

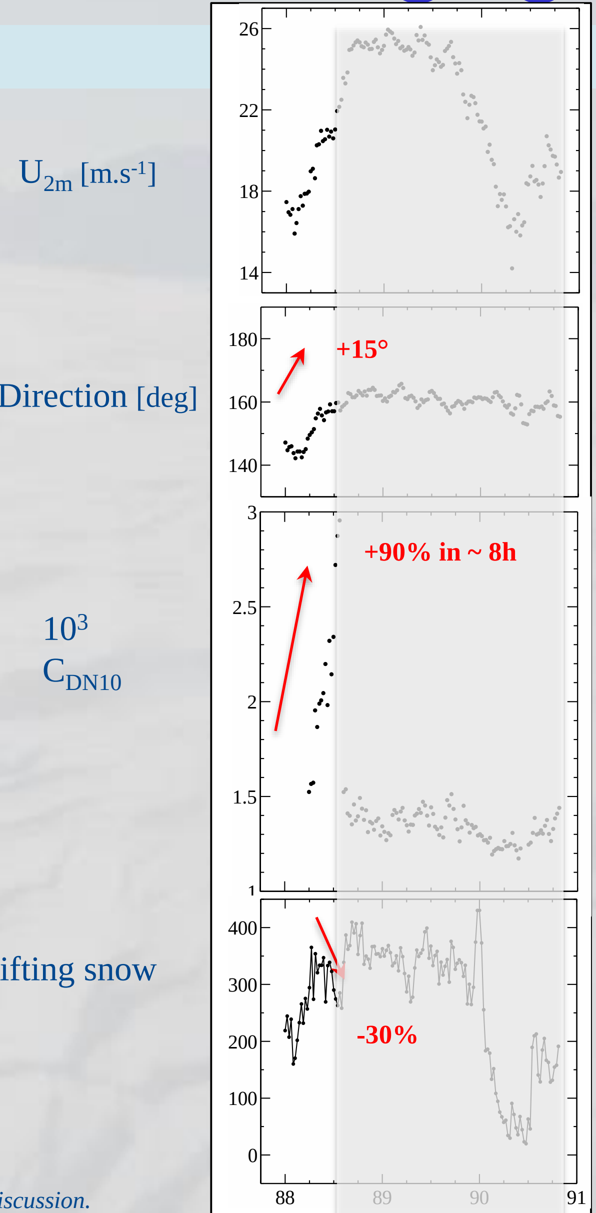
2. Focus on sastruggi

> Sastrugi aerodynamical adjustement



Drifting snow

Loss of wind momentum



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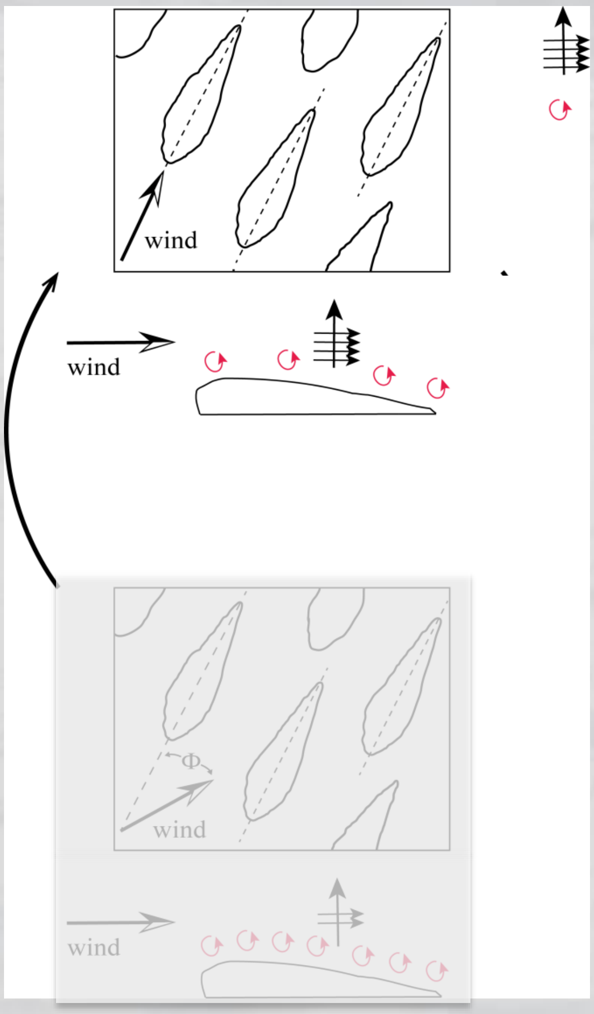
2. Focus on sastruggi

> Sastrugi aerodynamical adjustement



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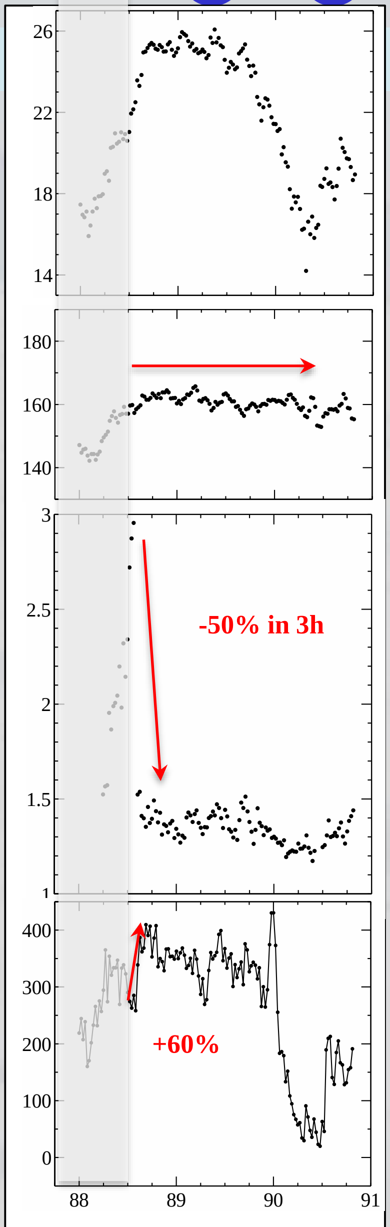


Amory C., Naaim-Bouvet F., Gallée H., Vignon E. (2015) – "Two cases of sastrugi aerodynamical adjustement" – *The Cryosphere Discussion.*

2. Focus on sastruggi

> **Real-time monitoring of surface roughness would advance understanding of physical process**

- Development of an automatic laser-scan (ANR Monisnow)

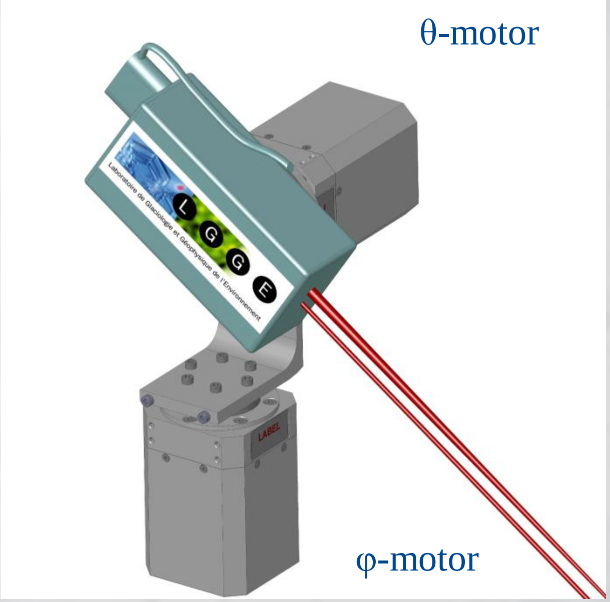
3. Automatic Laserscan

> Hardware

Lasermeter (DIMETIX FLS-CH 30 with Heater)
- red laser
- accuracy 3 mm
- max range 65 m (indoor ?)
- temperature range : -40◦C to +50◦C
- measure rate: 20 Hz

Two-axis rotation plateform
- designed and built by Alpes Instruments and LGGE
- precision : 0.05◦
- speed : 0.5 - 8 deg/s

Others :
- two-axis inclinometer
- embedded computer with linux
- Python/C driver softwares developed at LGGE



ALPES INSTRUMENTS

3. Automatic Laserscan

> Comparison with commercial laserscanner

Our laserscanner is RUGGED:

20 Hz with accuracy
(200 Hz possible, not tested).

Autonomous

- Tested at -70°C

- Operating at Dome C for 1 year (up to -80°C)

~12000€

Commercial laserscanners are FAST

1kHz - 1MHz

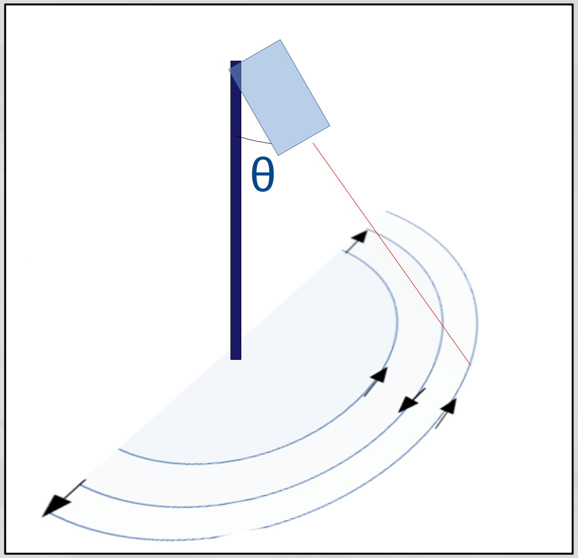
User-operated

~150000€

3. Automatic Laserscan

> Two operating modes

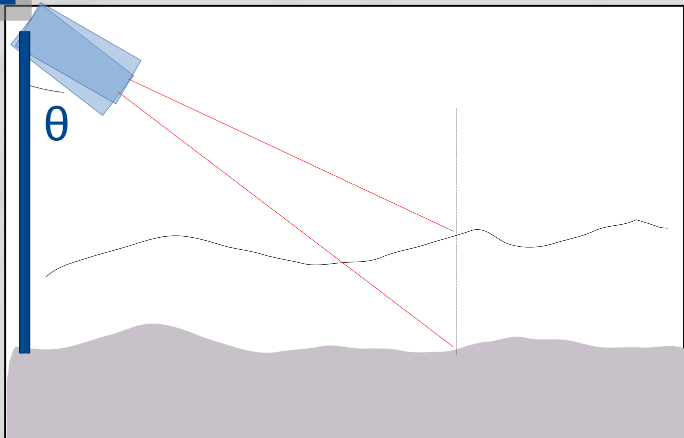
• Scan mode : produce a map of height



- A series of concentric arcs at constant speed from θ = 19◦ to 62◦

- θ increment and φ speed depends on tan(θ) to ensure constant resolution on the ground
- Duration : 4h
(once a day)
A scan is approx 200 000 points

• Spot mode : measure height at selected points



Search x,y by scanning in θ and return height at x,y

Duration : 1min / point
(65 points every 2h)

3. Automatic Laserscan

> Processing

-- θ,φ, range $\longrightarrow$ x,y,z

- rotation to ensure x,y is horizontal
(constant transformation for each site derived from 4 spheres set up in an horizontal plane)

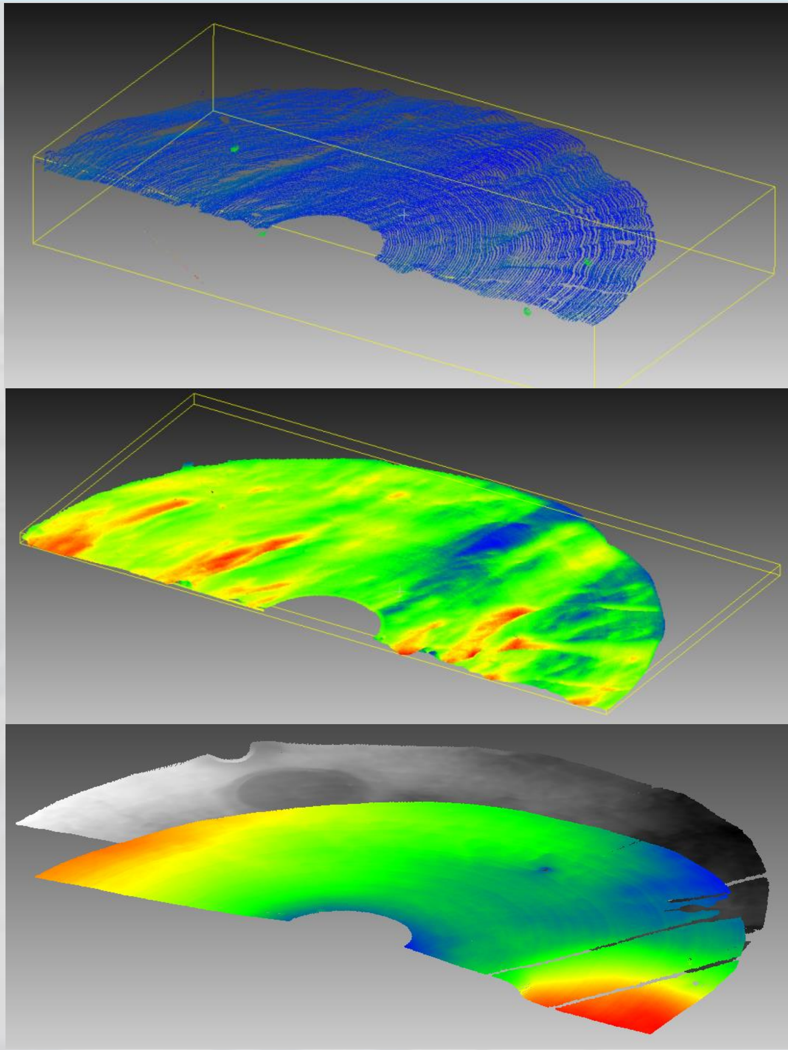
- remove known artifacts (cables, mast, spheres, …)

- filter : remove outliers
(departure from the local mean in a 5-cm radius disk is limited to 5 cm)

- mesh and resample on a regular grid

- substract the ground $\longrightarrow$ h(x,y)

- compute stats



3. Automatic Laserscan

> Deployment

Col de Porte, French Alps
2014-2015

Height:	5.2 m
Covered area:	$100m^2$
Daily scan	
Scan duration:	5h
Spot mode:	every 2h
Effective resolution:	5 cm

Dome C, Antarctica
2014-2015-2016

Height:	3.1m
Covered area:	$50m^2$
Daily scan	
Scan duration:	4h
Effective resolution:	3 cm

Lac Blanc Pass, French Alps
2015-2016

Height:	6 m
Covered area:	$180\ m^2$
Daily scan	
Scan duration:	4h
Effective resolution:	5 cm

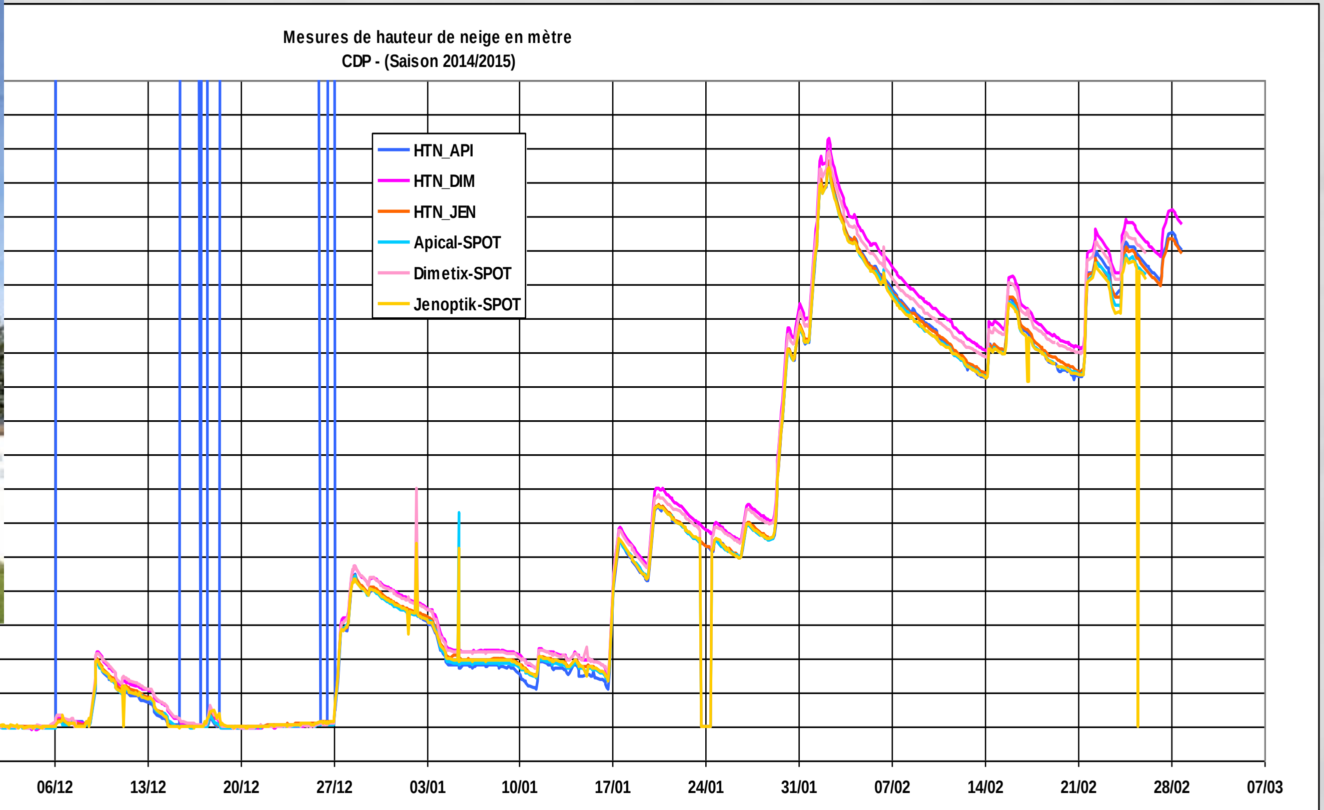
3. Automatic Laserscan

> Results (laser-scan in spot-mode)

Col de Porte, French Alps

- Intrinsic accuracy is 3 mm of the telemeter
- Intrinsic accuracy of the plateform: 0.05°

Comparison with 3 telemeters deployed for SPICE (laserscan is in spot mode)

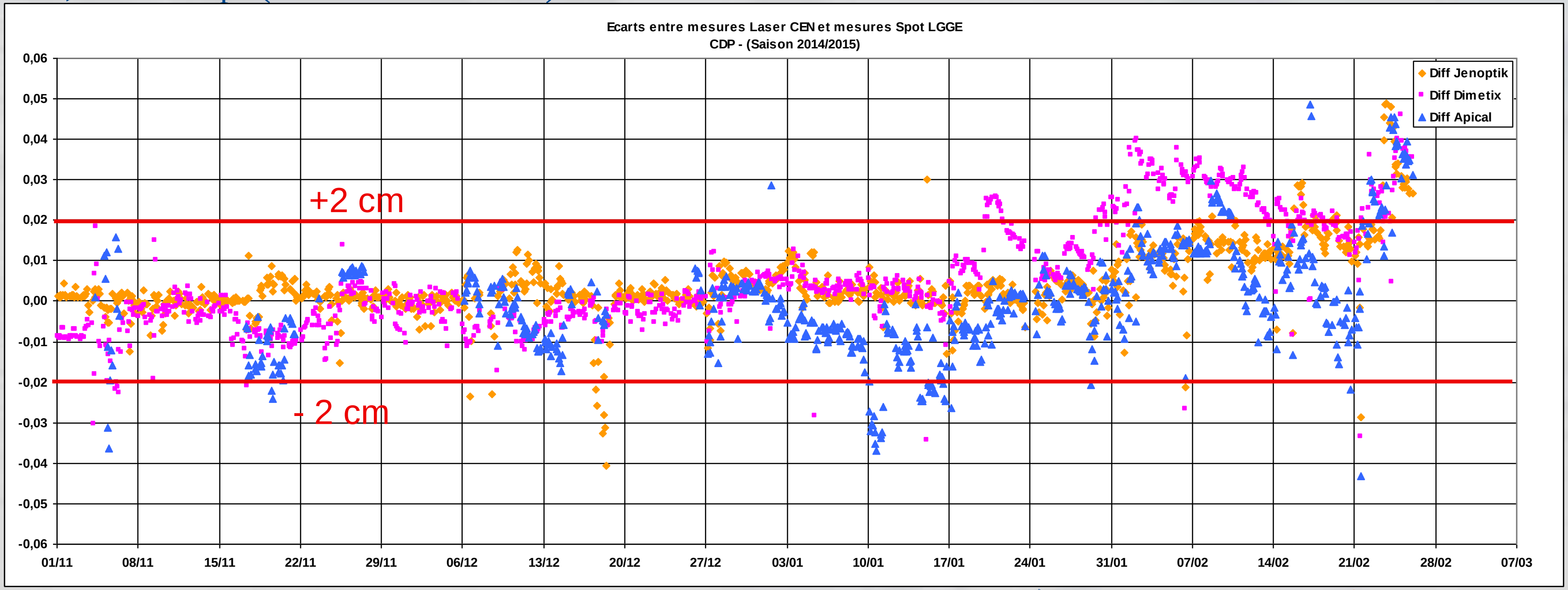


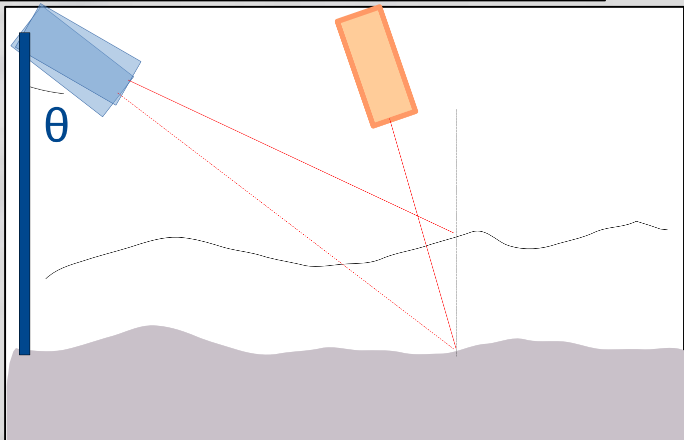
3. Automatic Laserscan

> Results (laser-scan in spot-mode)

Col de Porte, French Alps (same with residuals)

-



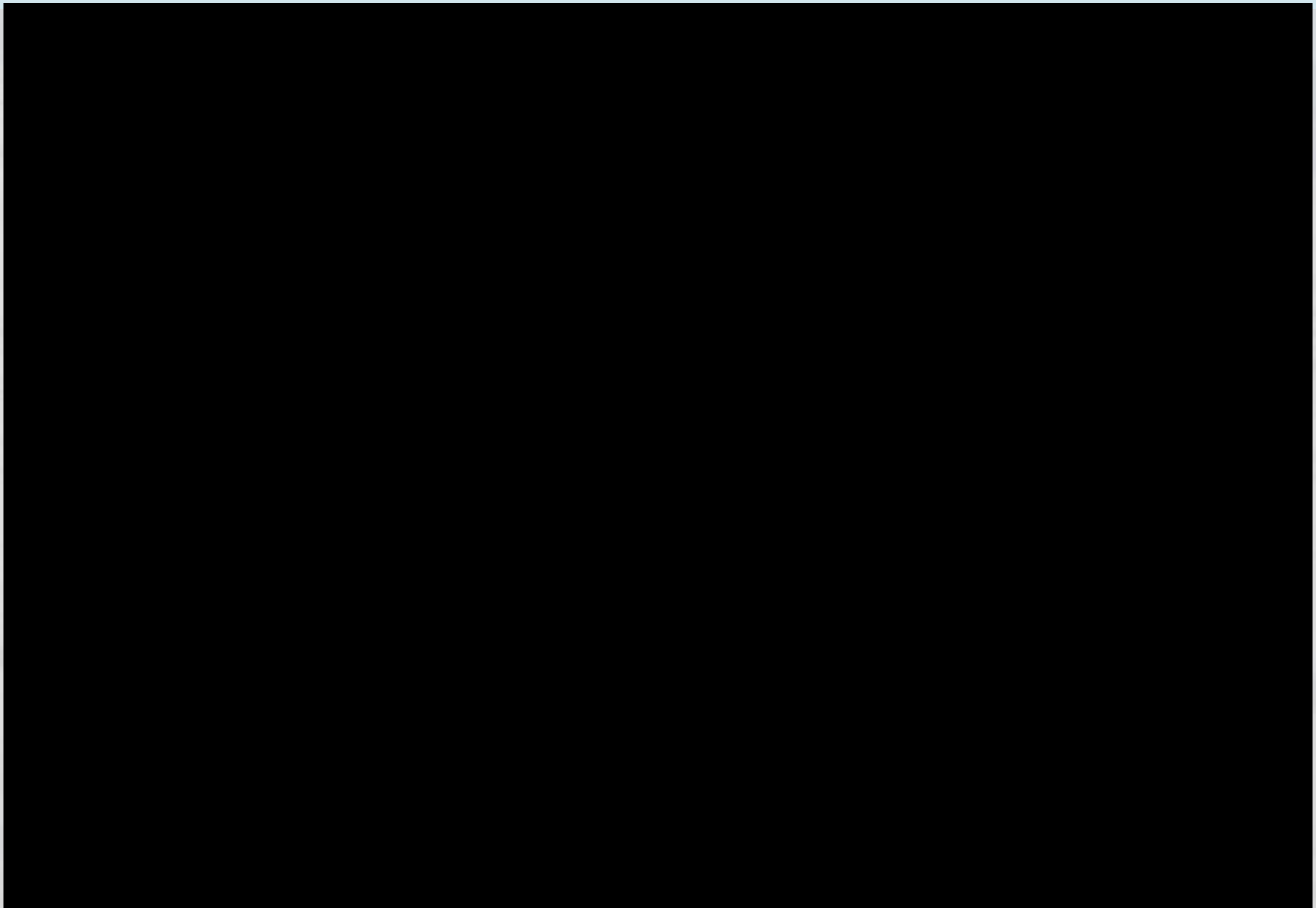


- Part of the residuals is geometric (spot mode / fixed angle)

- Probable accuracy is around 1 cm

3. Automatic Laserscan

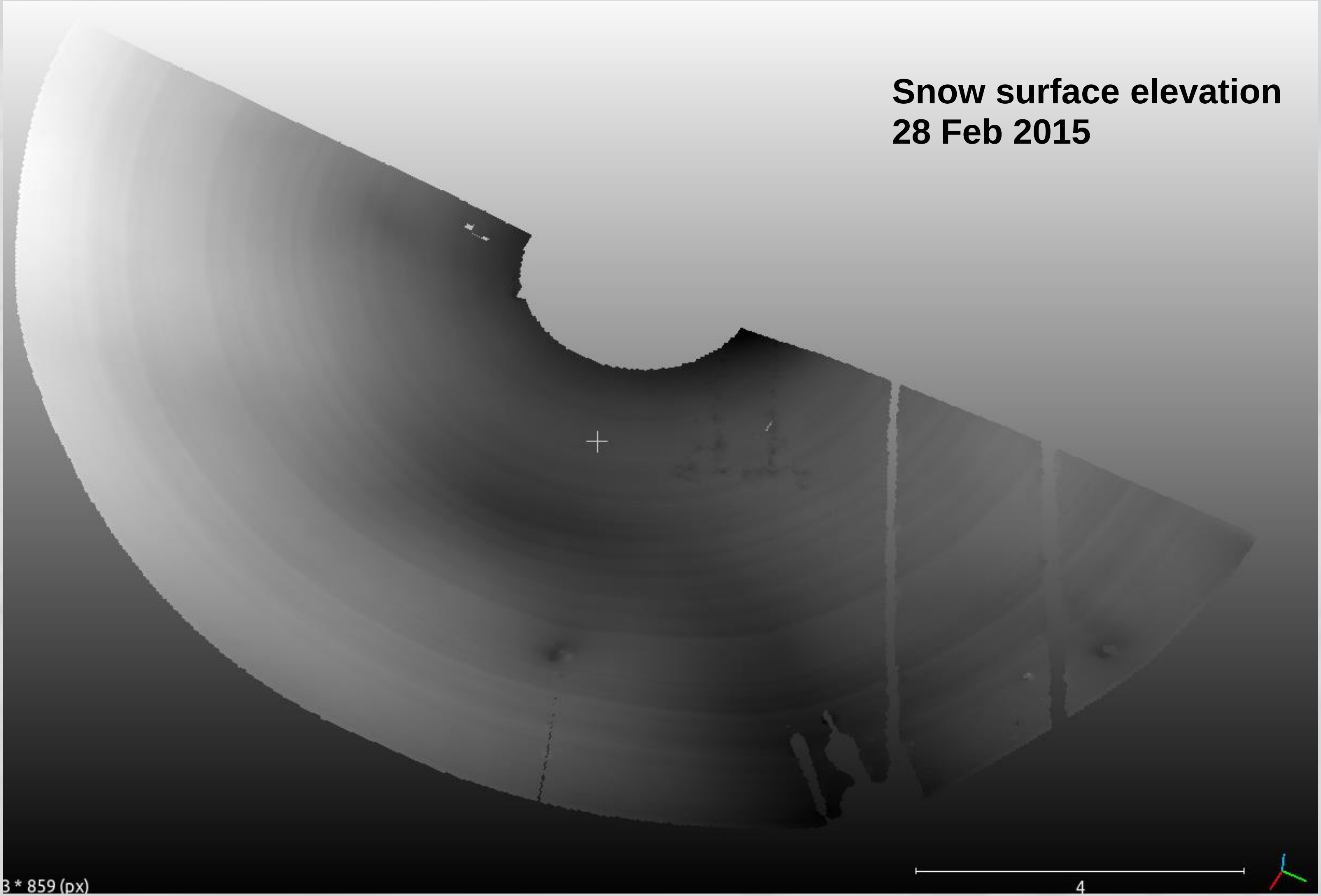
> Col de Porte :



Snow depth is uniform at Col de Porte in the area selected for SPICE height comparison

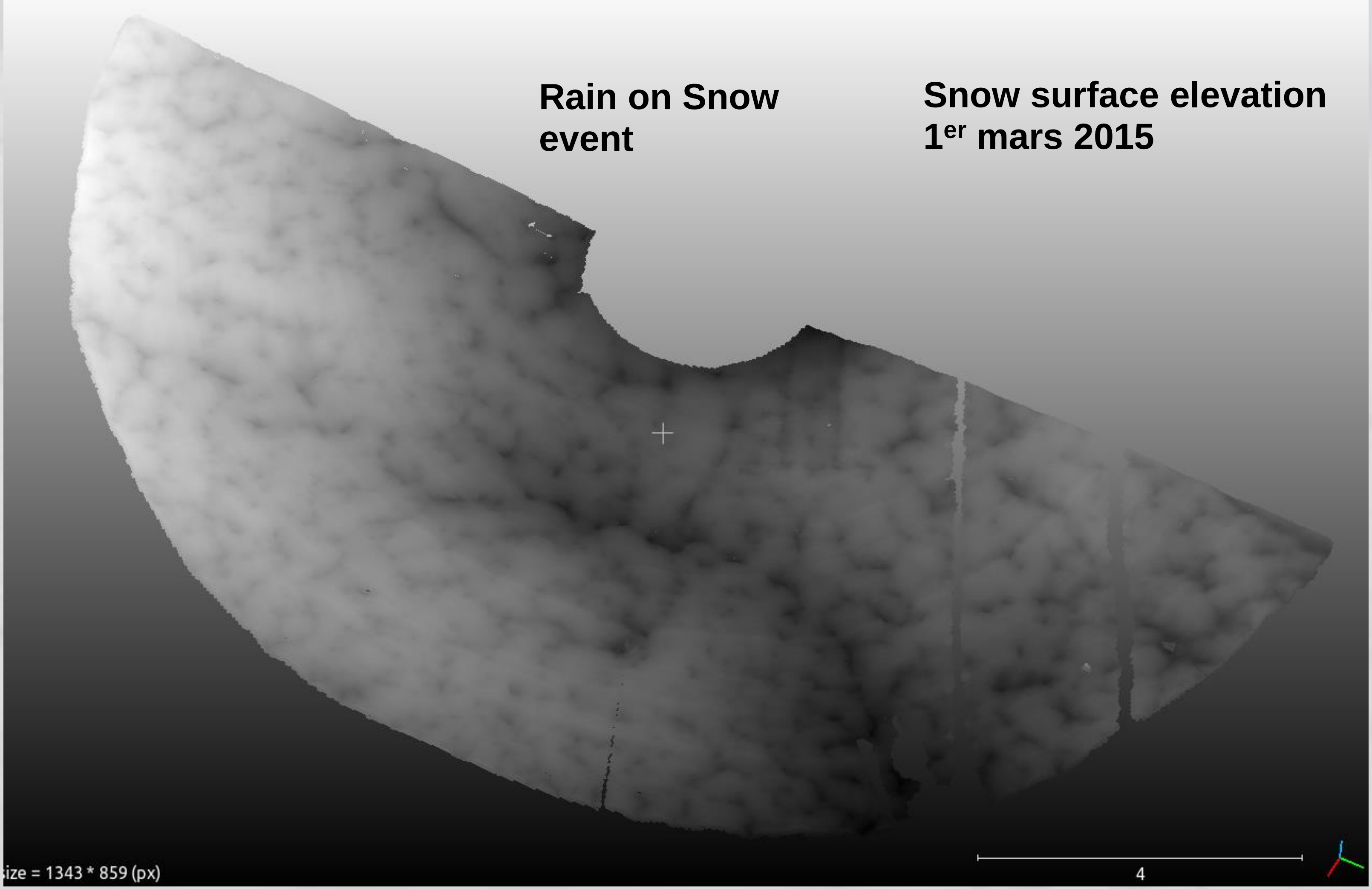
3. Automatic Laserscan

> Col de Porte : added value of the laserscan



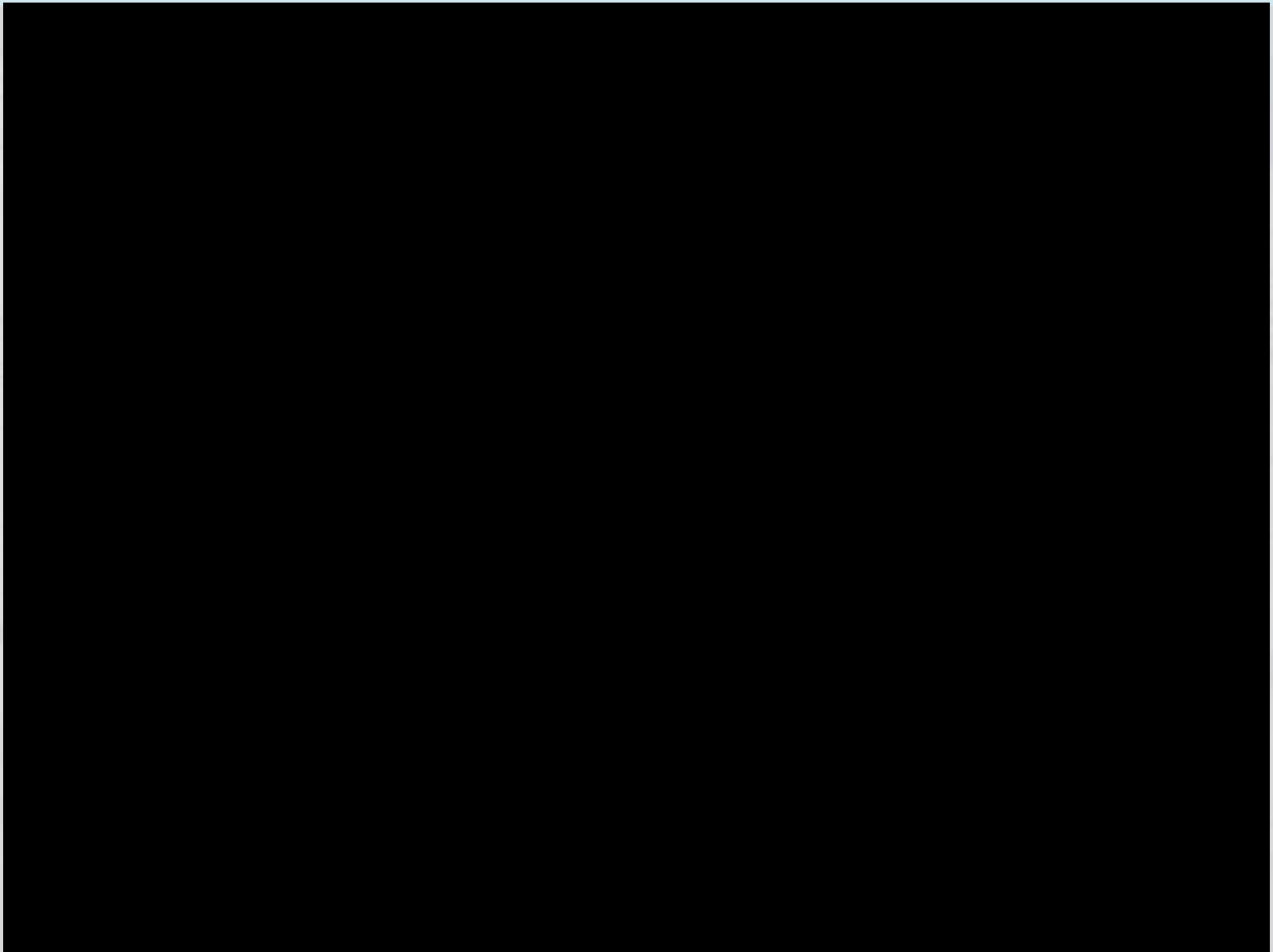
3. Automatic Laserscan

> Col de Porte : added value of the laserscan



3. Automatic Laserscan

> Col du Lac Blanc



3. Automatic Laserscan

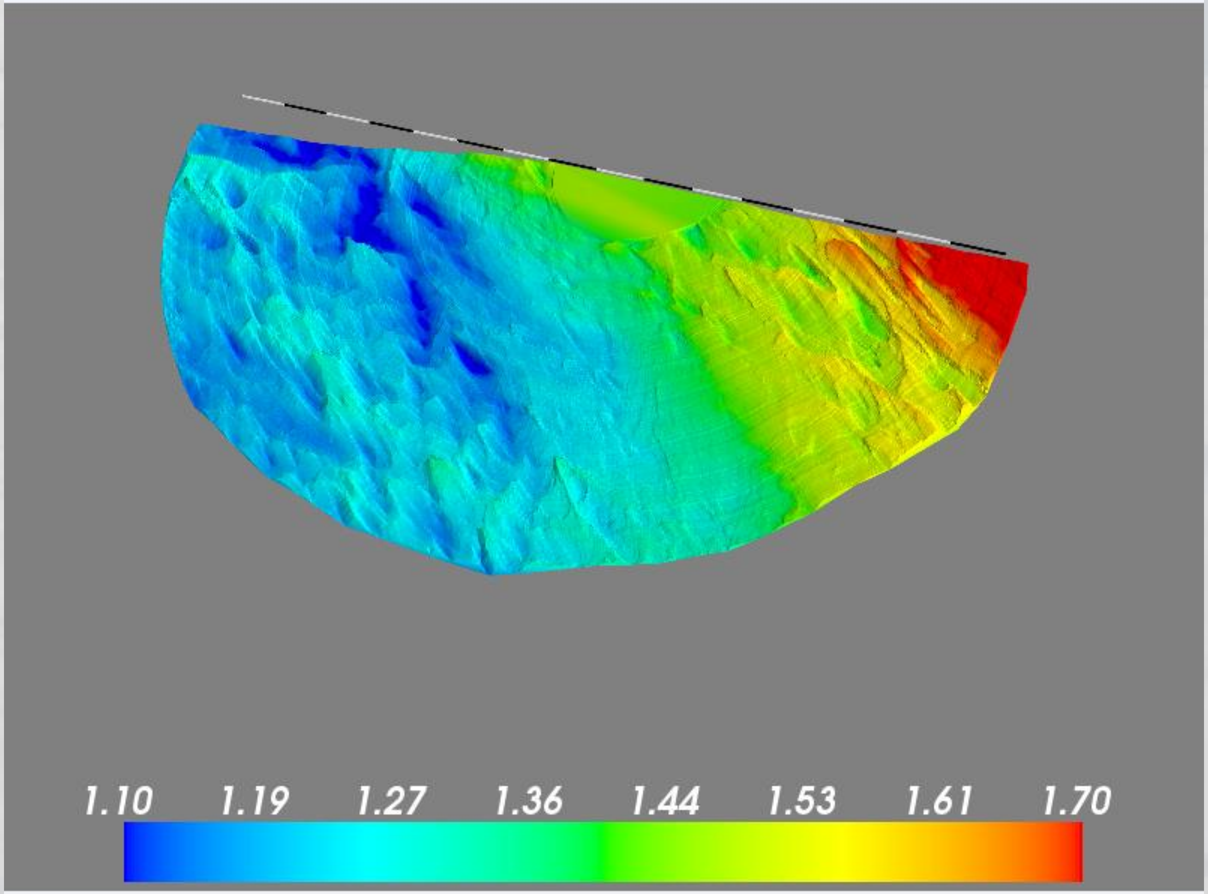
> Col du Lac Blanc

Data acquisition problems during riming events

… which is not limited to the laserscan.

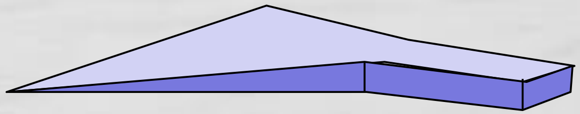
3. Automatic Laserscan

> Col du Lac Blanc



> Characterization of sastrugi

Drag force is function of frontal area
Frontal area = area (measured on the vertical crosswind lateral plane) seen by the wind



Sketch of an idealized sastruga

> Characterization of sastruggi

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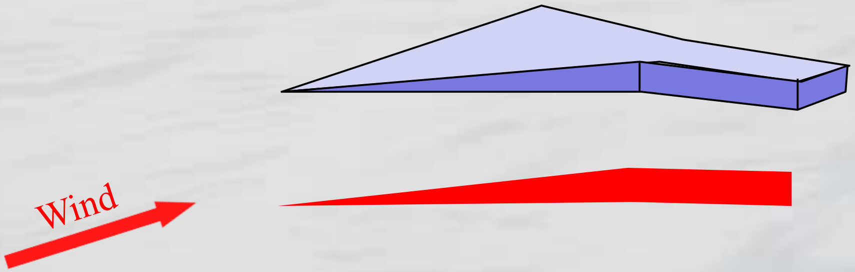
Frontal area = area (measured on the vertical crosswind lateral plane) seen by the wind



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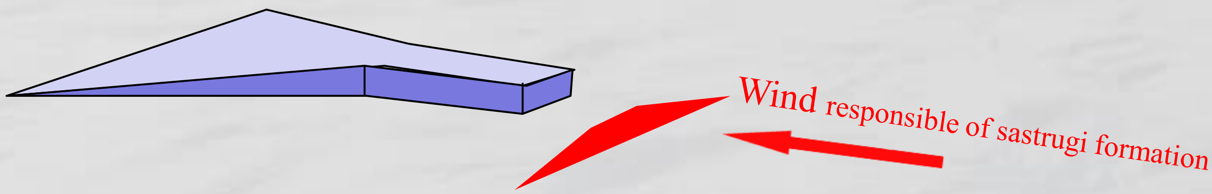
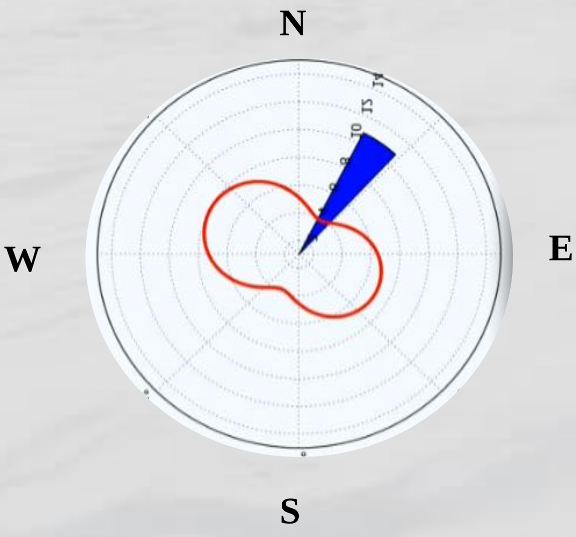
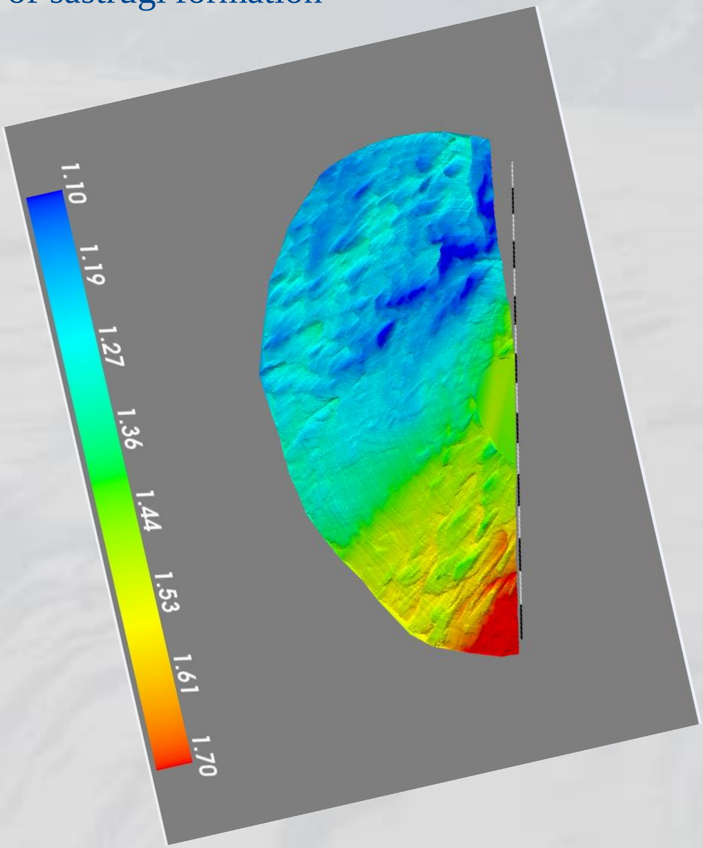


Frontal area is minimum for the prevailing wind direction responsible of sastrugi formation

> Characterization of sastruggi

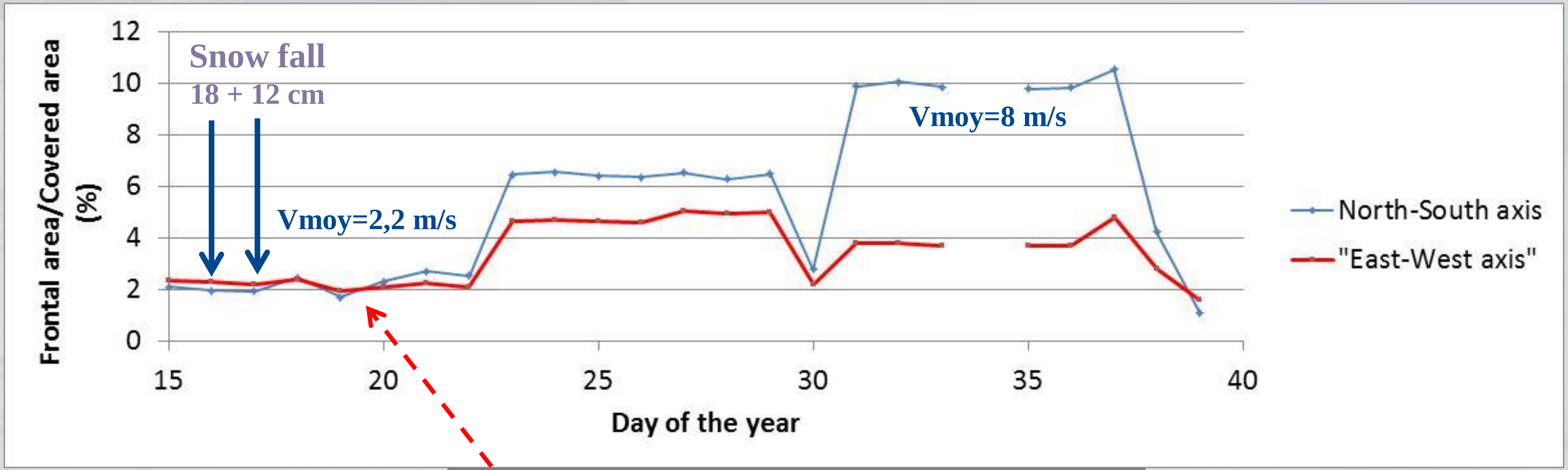
Frontal area is minimum for the prevailing wind direction responsible of sastrugi formation

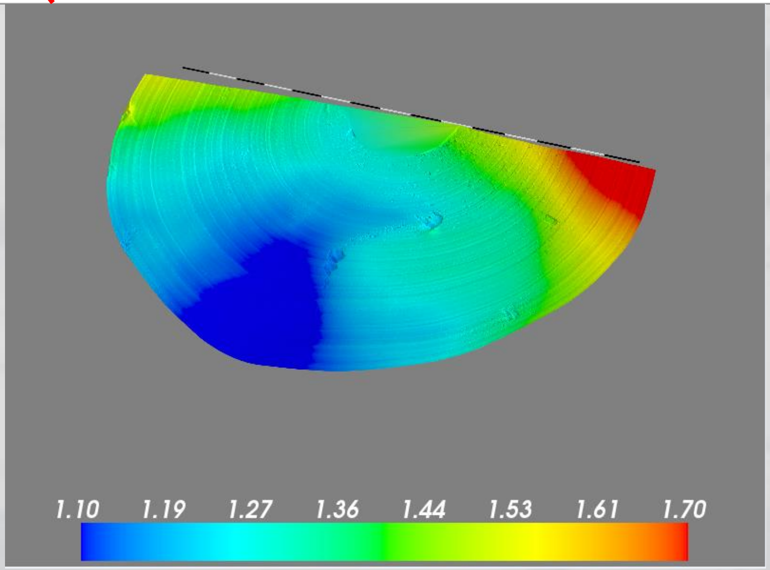




3. Automatic Laserscan

> Col du Lac Blanc : Sastrugi morphometry and change in time





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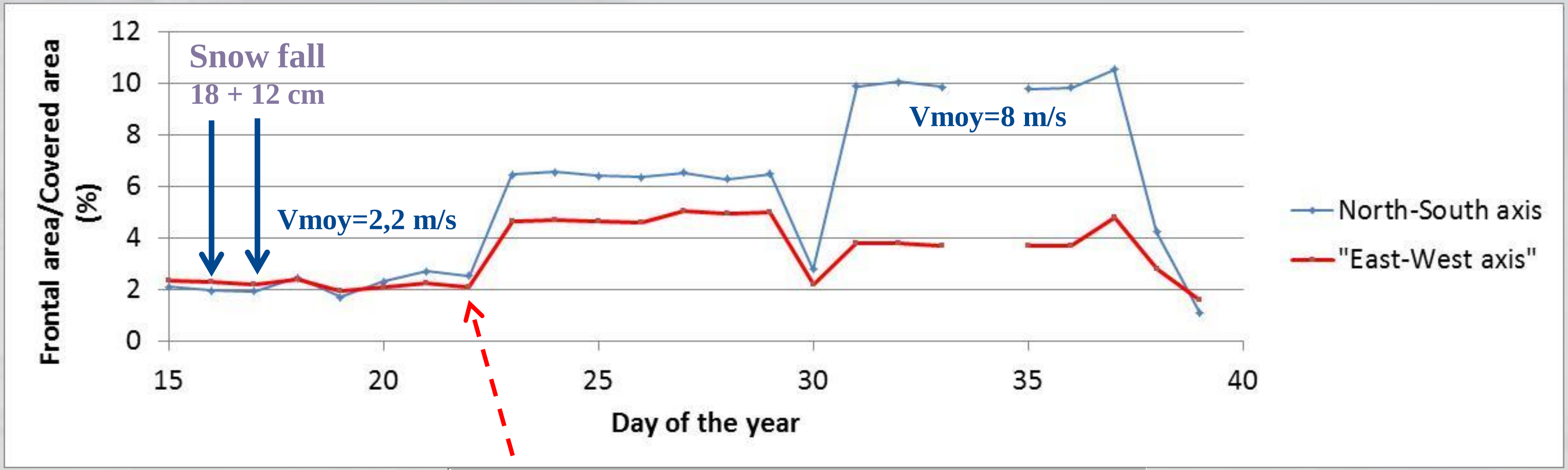

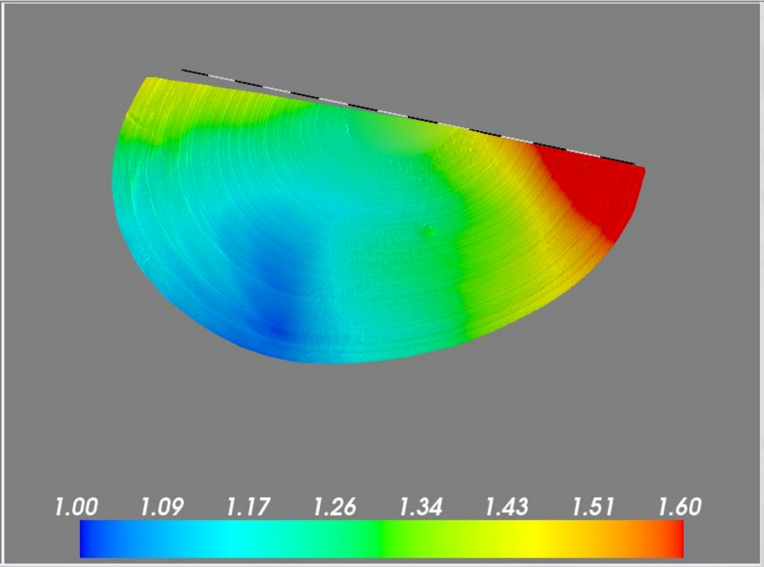

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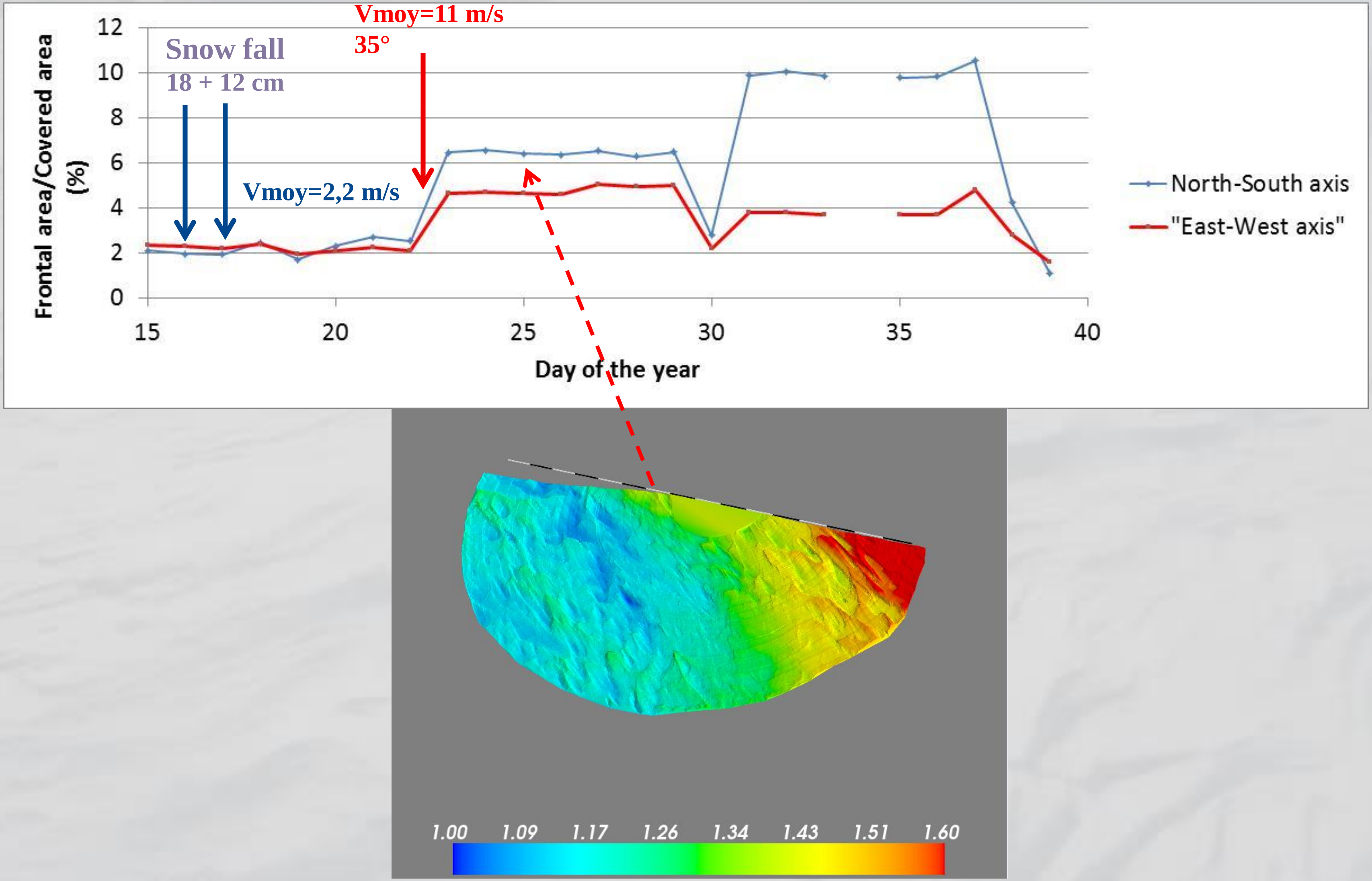

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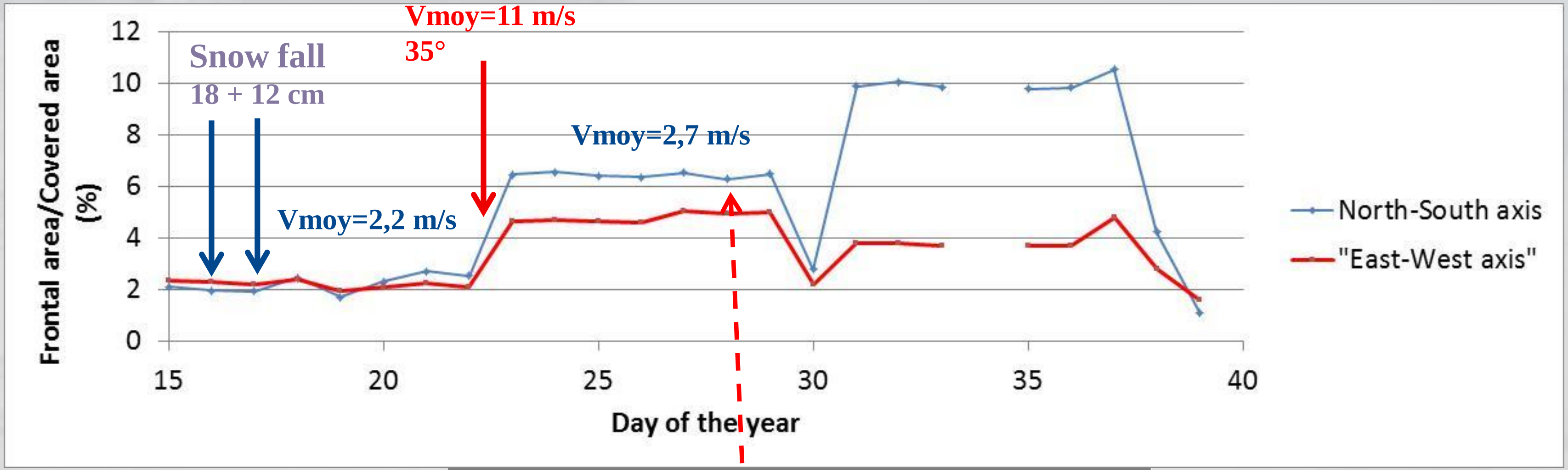

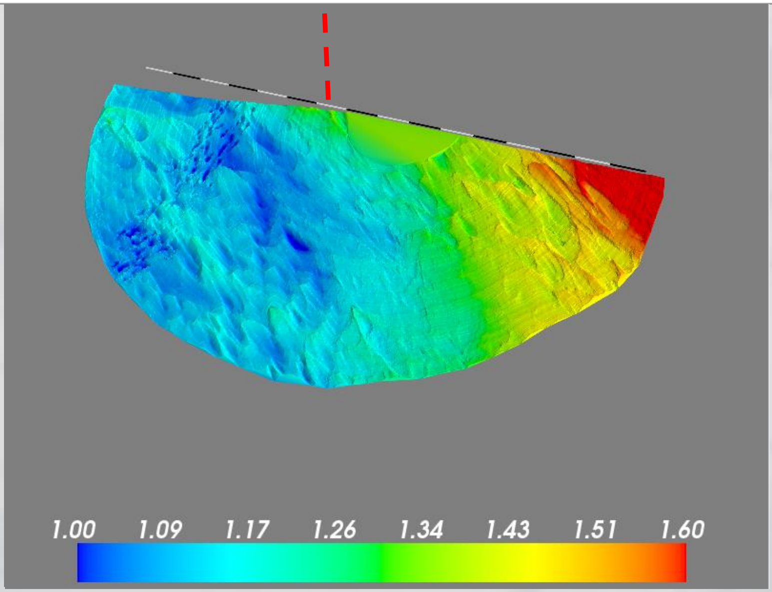

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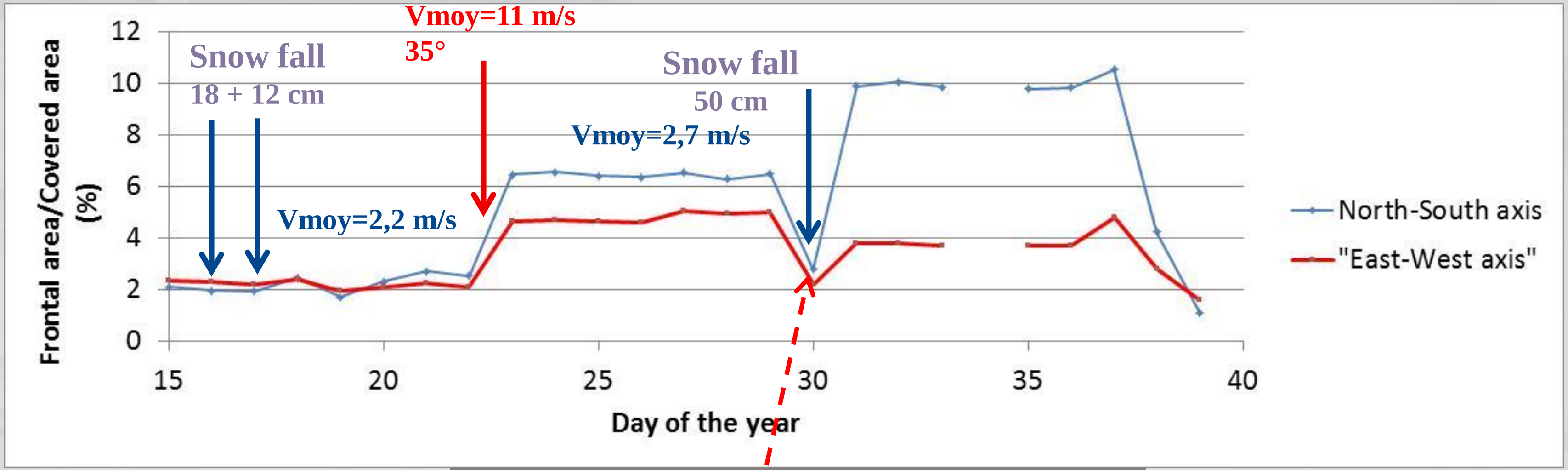

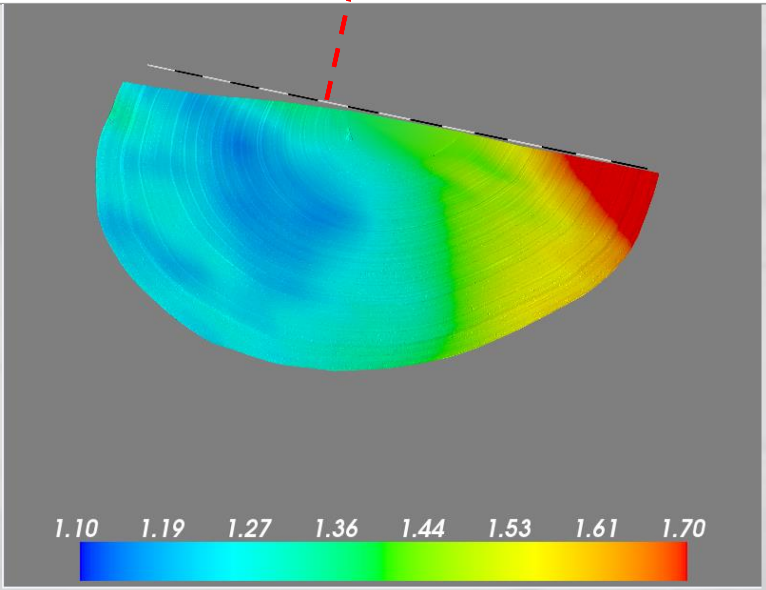

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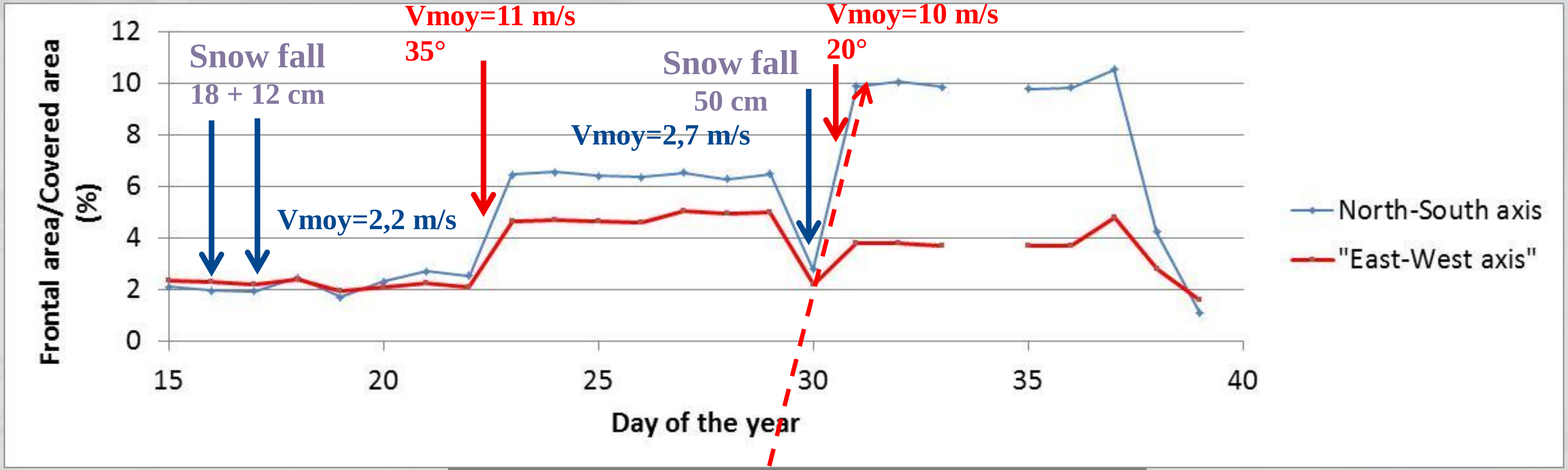

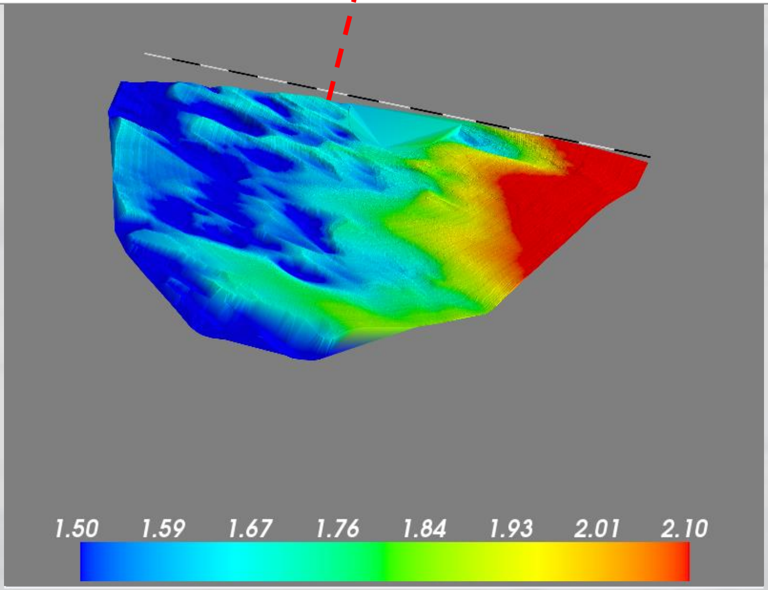

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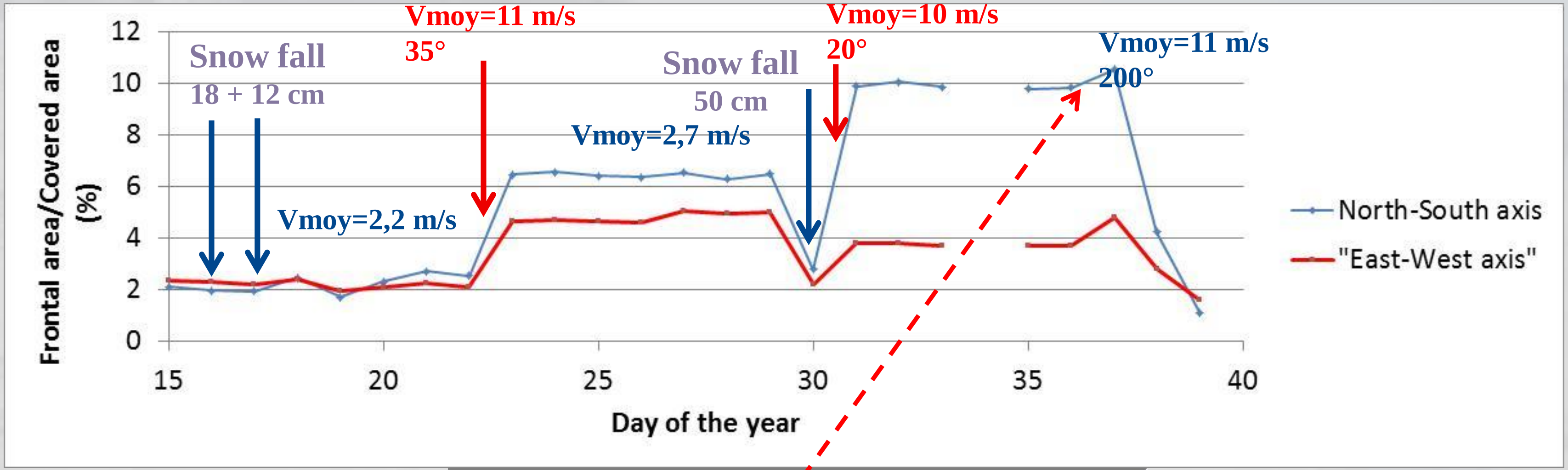

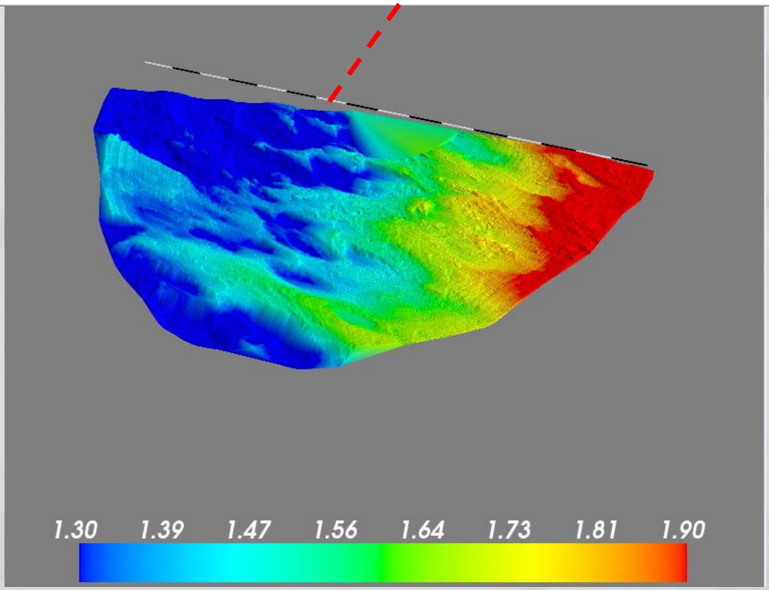

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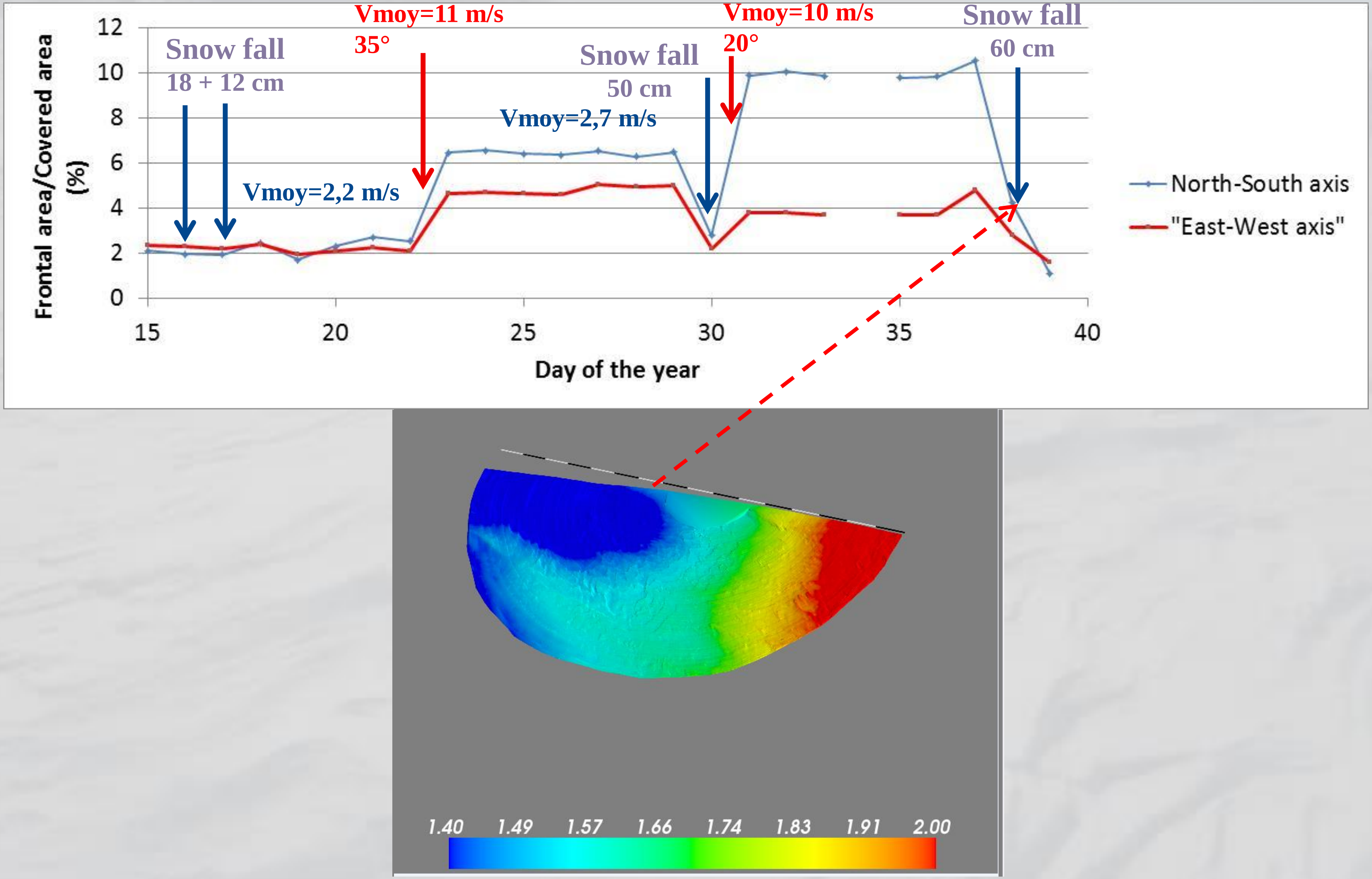

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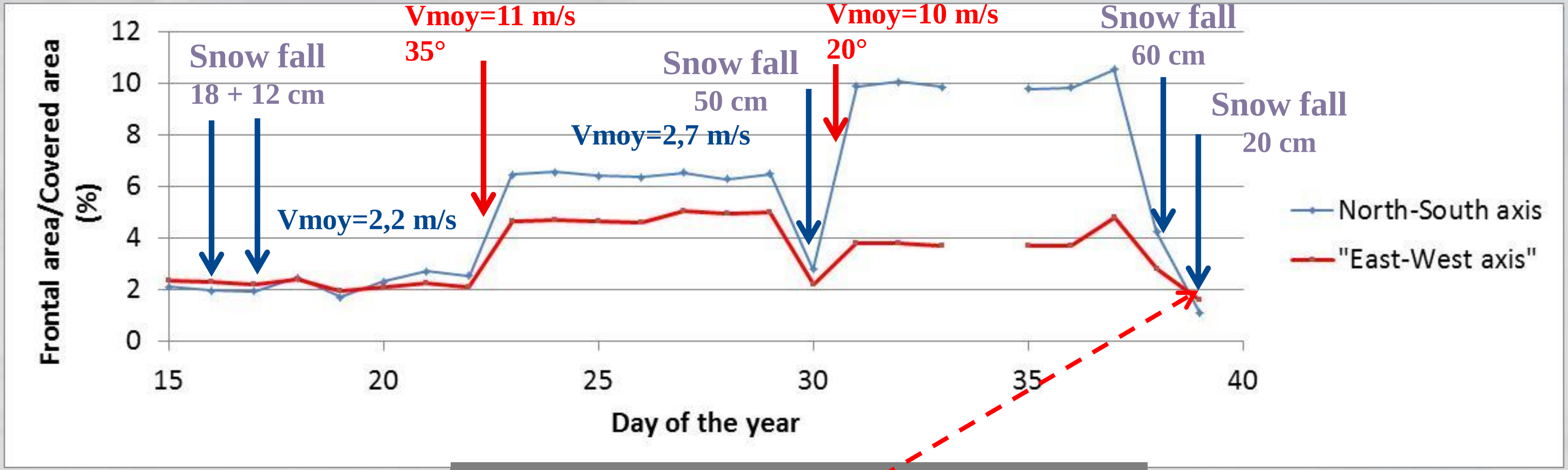
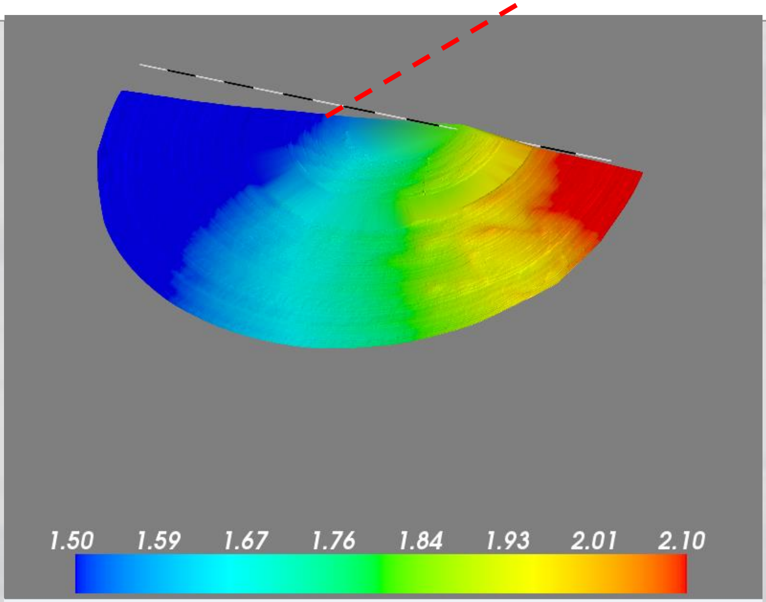




3. Automatic Laserscan

> Conclusions and perspectives

- 2 rugged laserscans have collected ~ 600 scans during two winters in Col de Porte, Dome C and Col du Lac Blanc

- Precision is 1 cm and spatial resolution is 3-5 cm (height dependent)

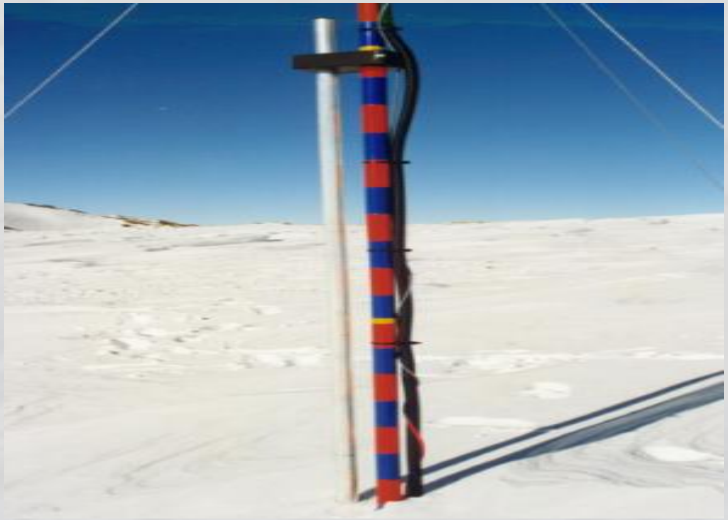
ean-martial.cohard@ujf-grenoble.fr

- A lot to learn about wind-form features : data processing in progress (roughness in windy area)

- Other applications : melt-form features, snow cover under trees

3. Faut-il écouter, attraper ou regarder les flocons de neige ?

> Capteurs acoustiques



3. Faut-il écouter, attraper ou regarder les flocons de neige ?

> Capteurs optiques