

Observations et modélisation des conditions d'enneigement dans les domaines skiables

impact du damage et de la production de neige

Spandre P.^{1,2,*}, François H.², Thibert E.²,
Morin S.¹, George-Marcelpoil E.², Lafaysse M.¹, Lejeune Y.¹

¹ Météo-France - CNRS, Centre d'Etudes de la Neige
² Université Grenoble Alpes, Irstea,
* pierre.spandre@irstea.fr

Un constat



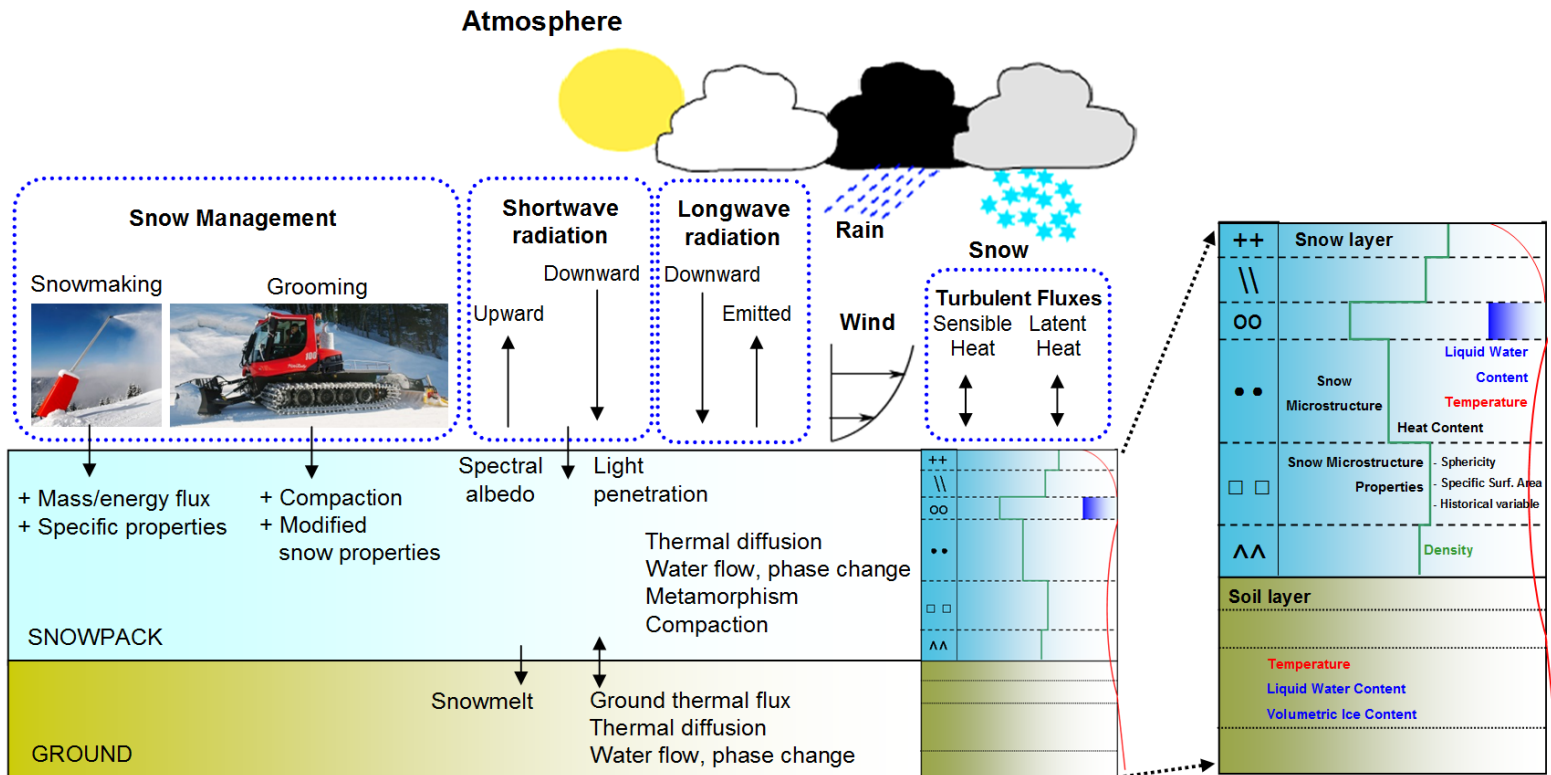
Chamrousse, 27 Janvier 2016



Tignes, 7 Mai 2015

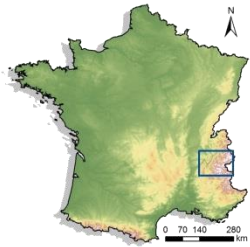
2014. 5. 7 14:58

Développement Crocus - Resort

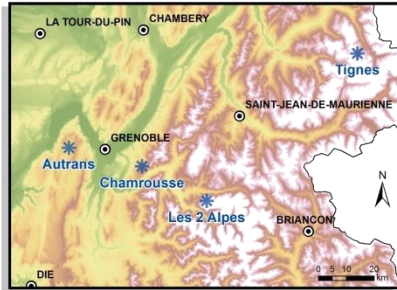


Spandre, P., Morin, S., Lafaysse, M., George-Marcelpoil, E., Francois, H., Lejeune, Y., 2016. **Integration of snow management processes into a detailed snowpack model.** Cold Regions Science and Technology doi :10.1016/j.coldregions.2016.01.002

Suivi saisonnier



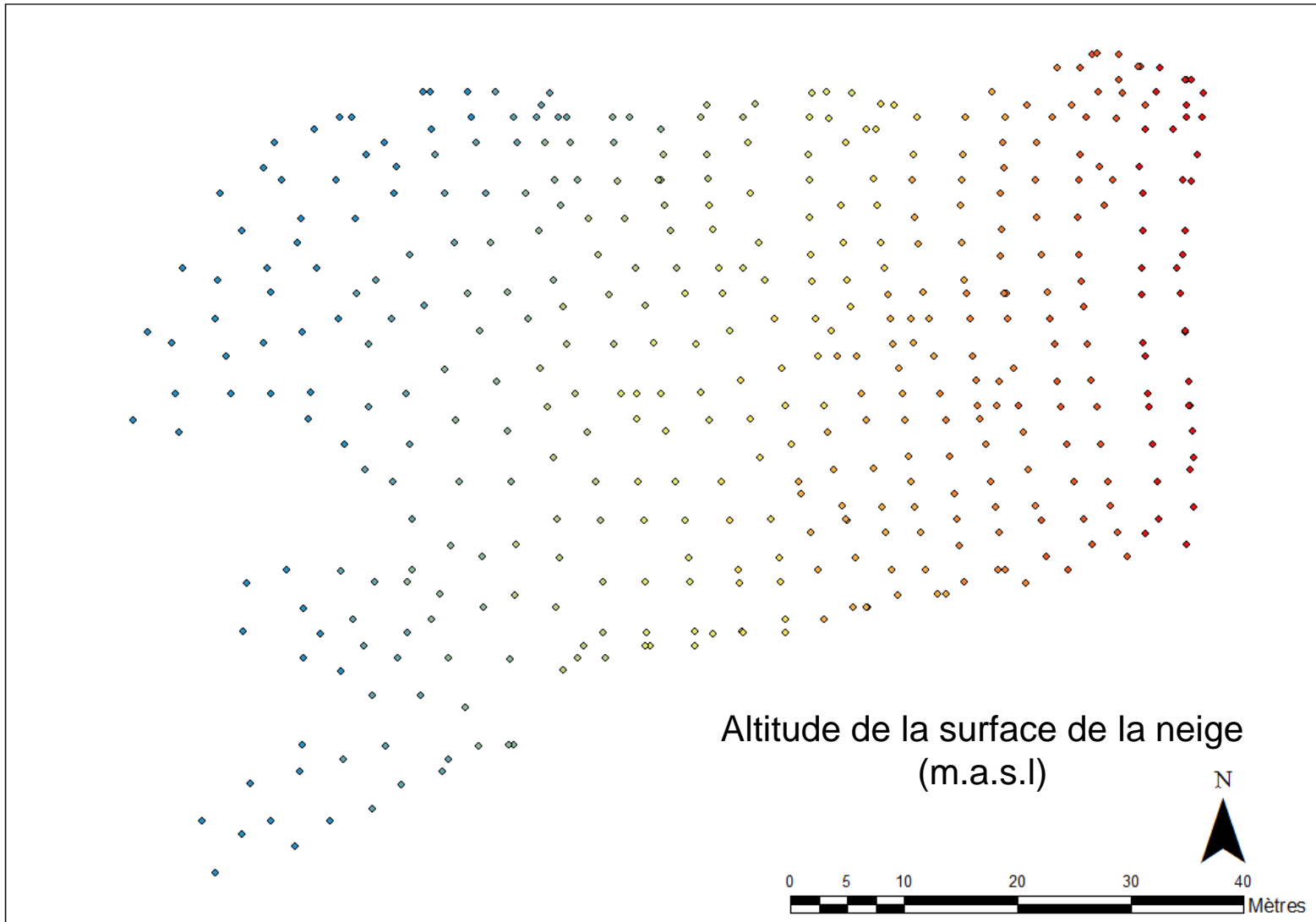
Major cities Altitude 4767 m.
Resorts 0 m.



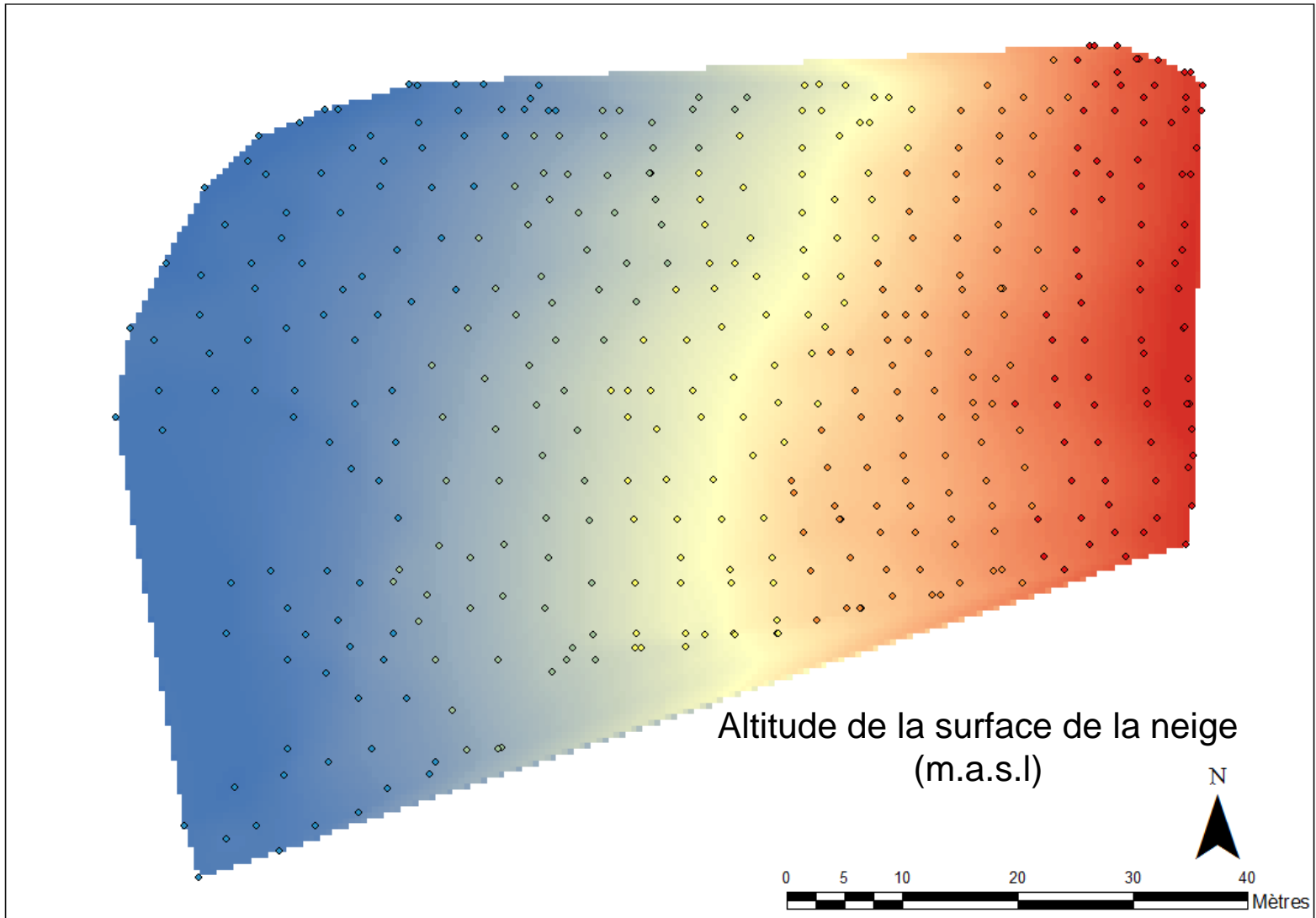
Suivi saisonnier



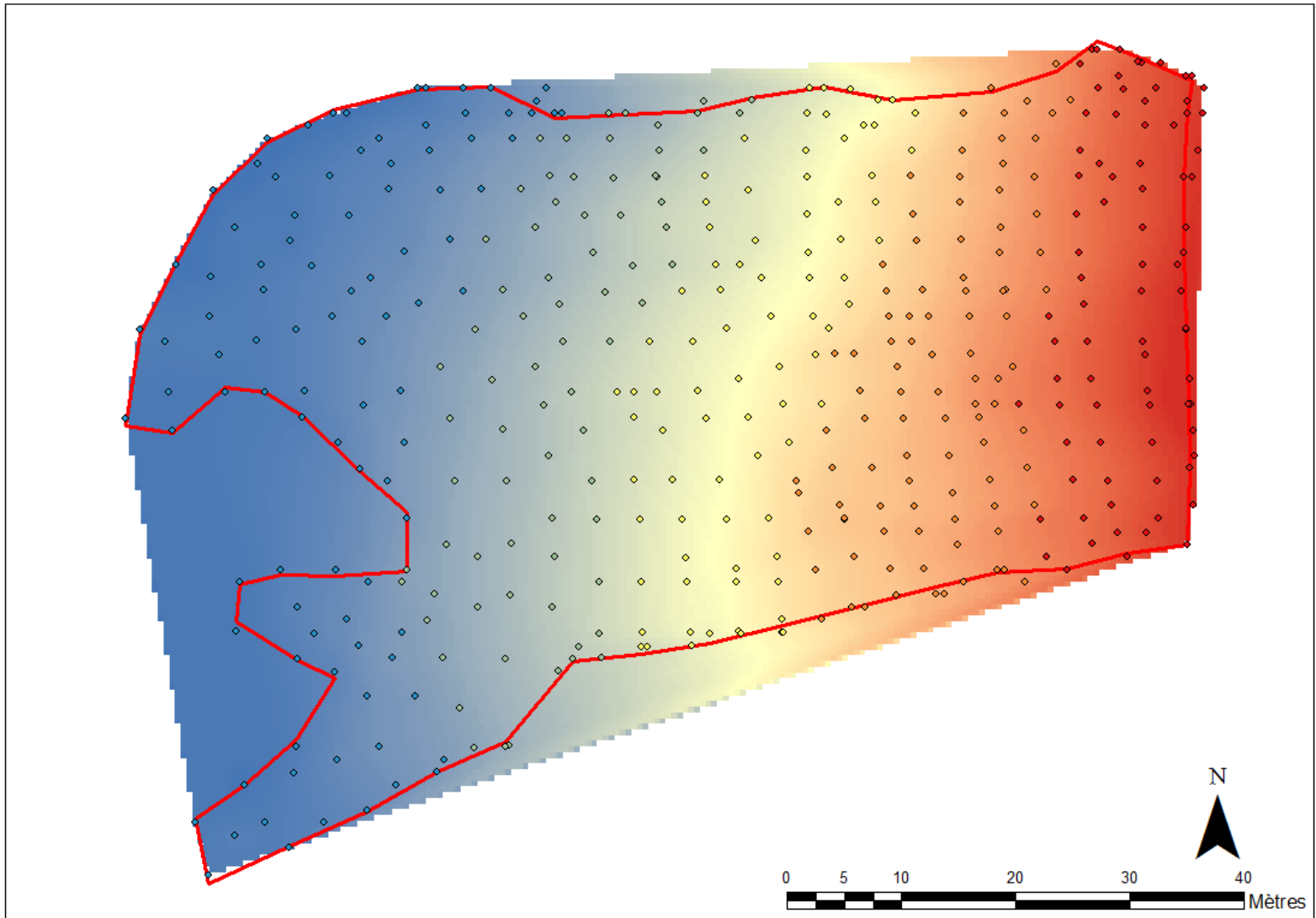
Lever GPS Différentiel



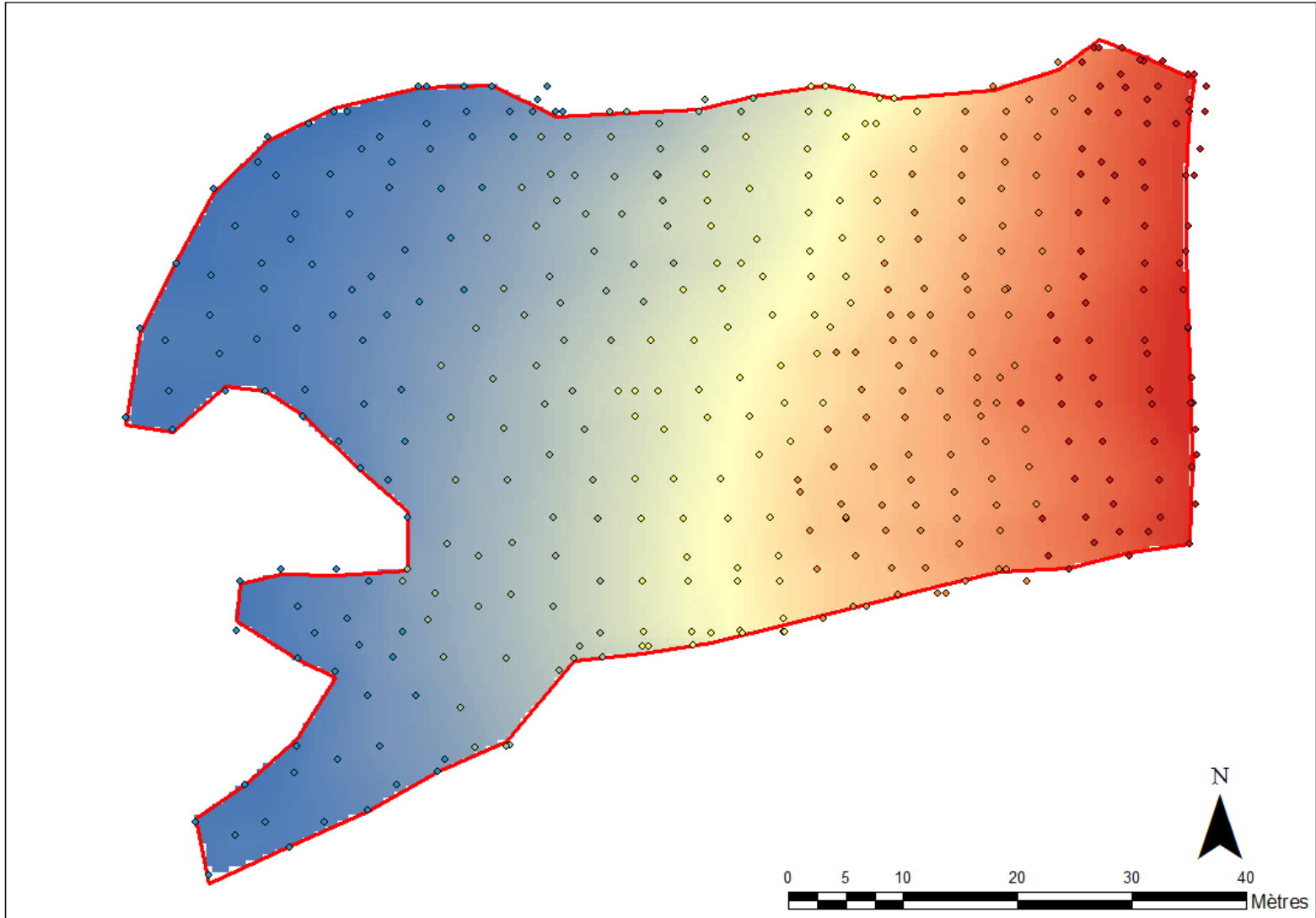
Interpolation



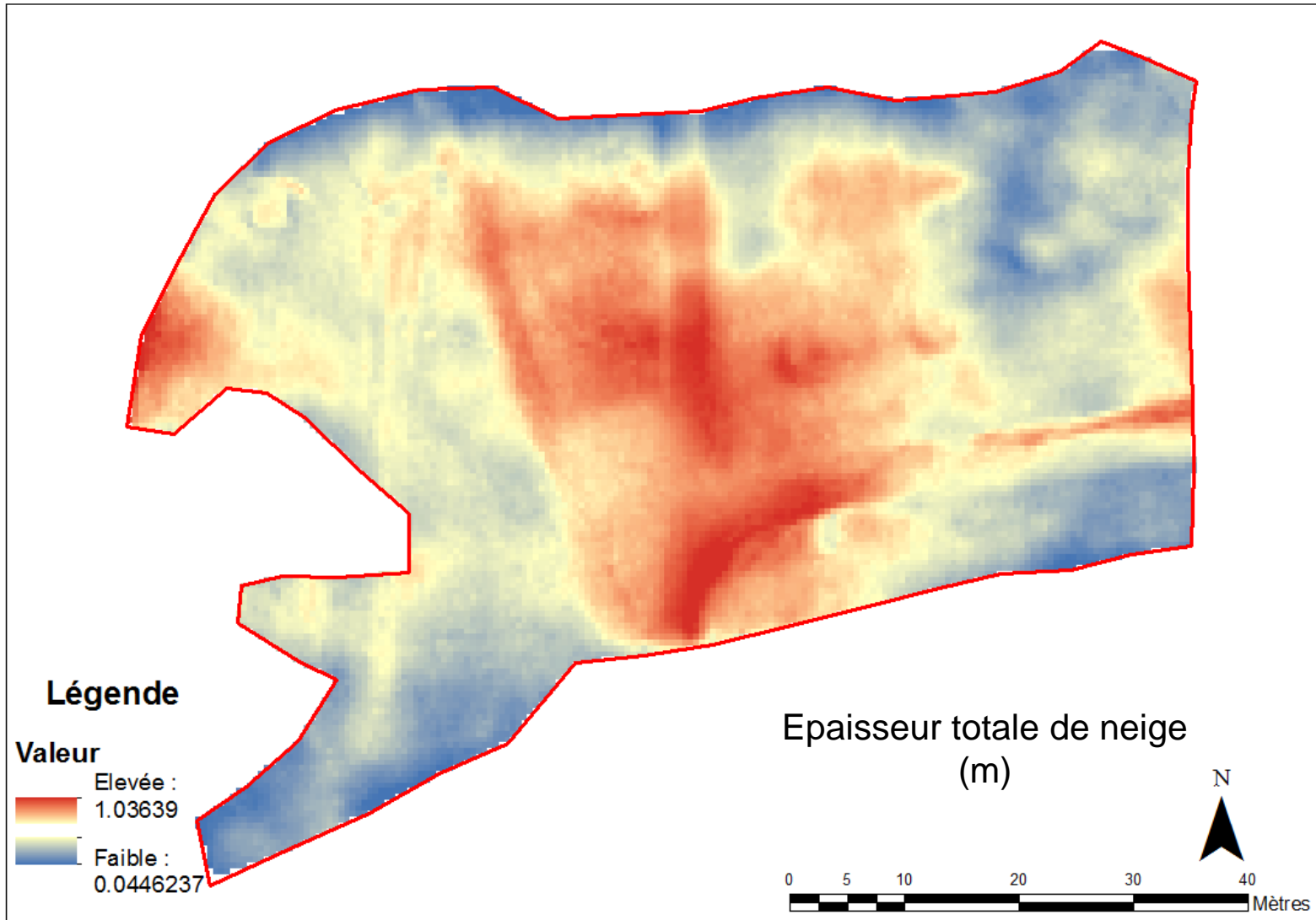
Contour de piste



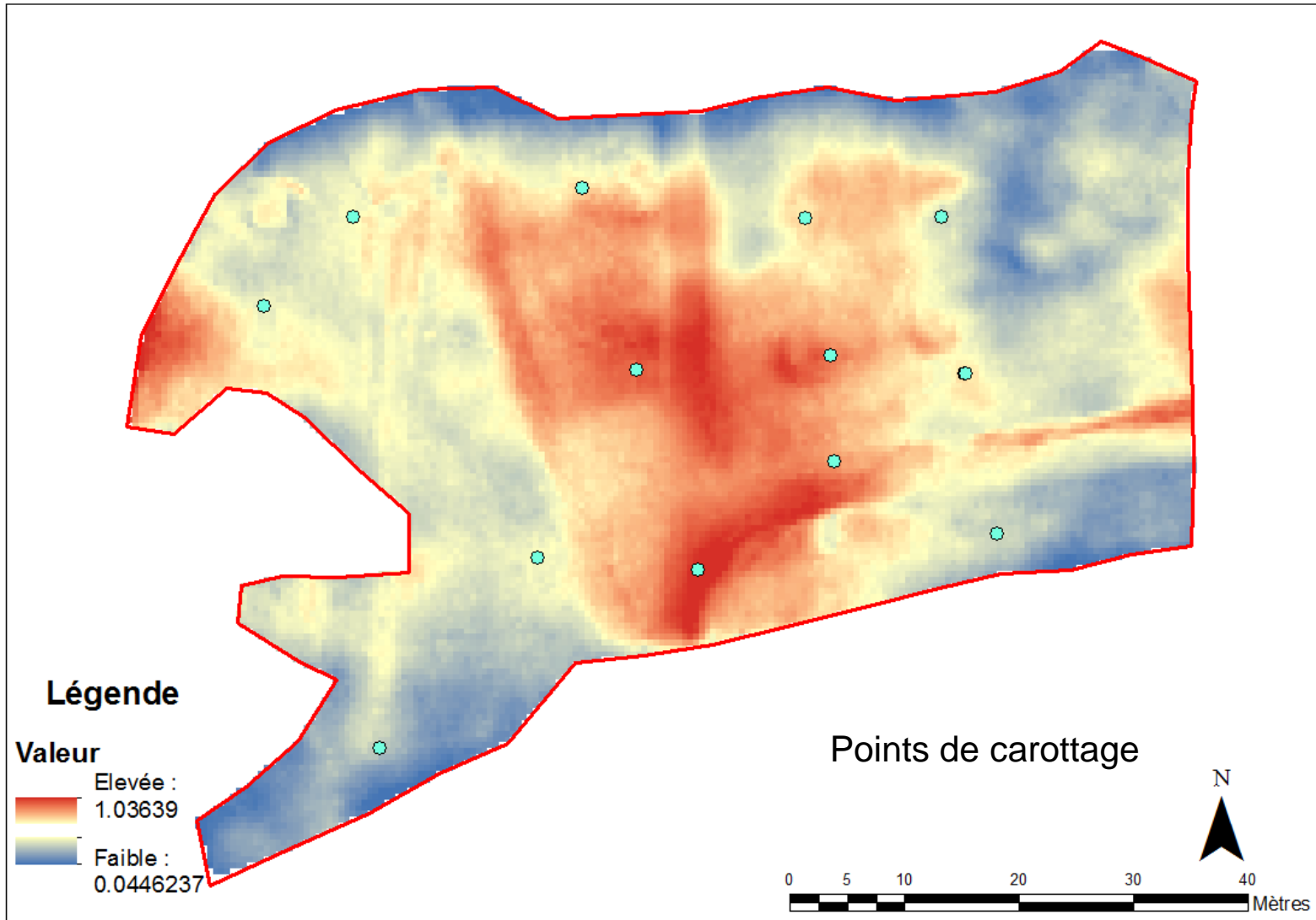
Détourrage



Calcul de HTN



Mesure de densité

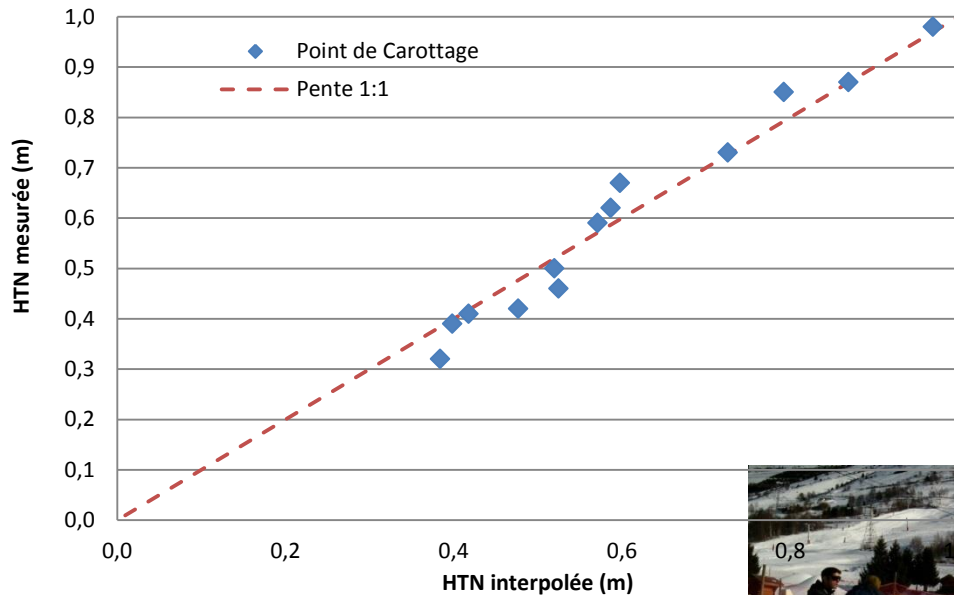


Incertitudes

Evaluation par méthode laser scan

Evaluation sur les points de carottage

Evaluation HTN sur points de carottage
2016 - 01 - 20



Incertitudes retenues:

HTN : 5 cm

Densité : 30 kg m⁻³

Equivalent en Eau (kg m⁻²)

$$\frac{\sigma_{SWE}}{SWE_{moy}} = \frac{\sigma_{Rho}}{Rho_{moy}} + \frac{\sigma_{SD}}{SD_{moy}}$$

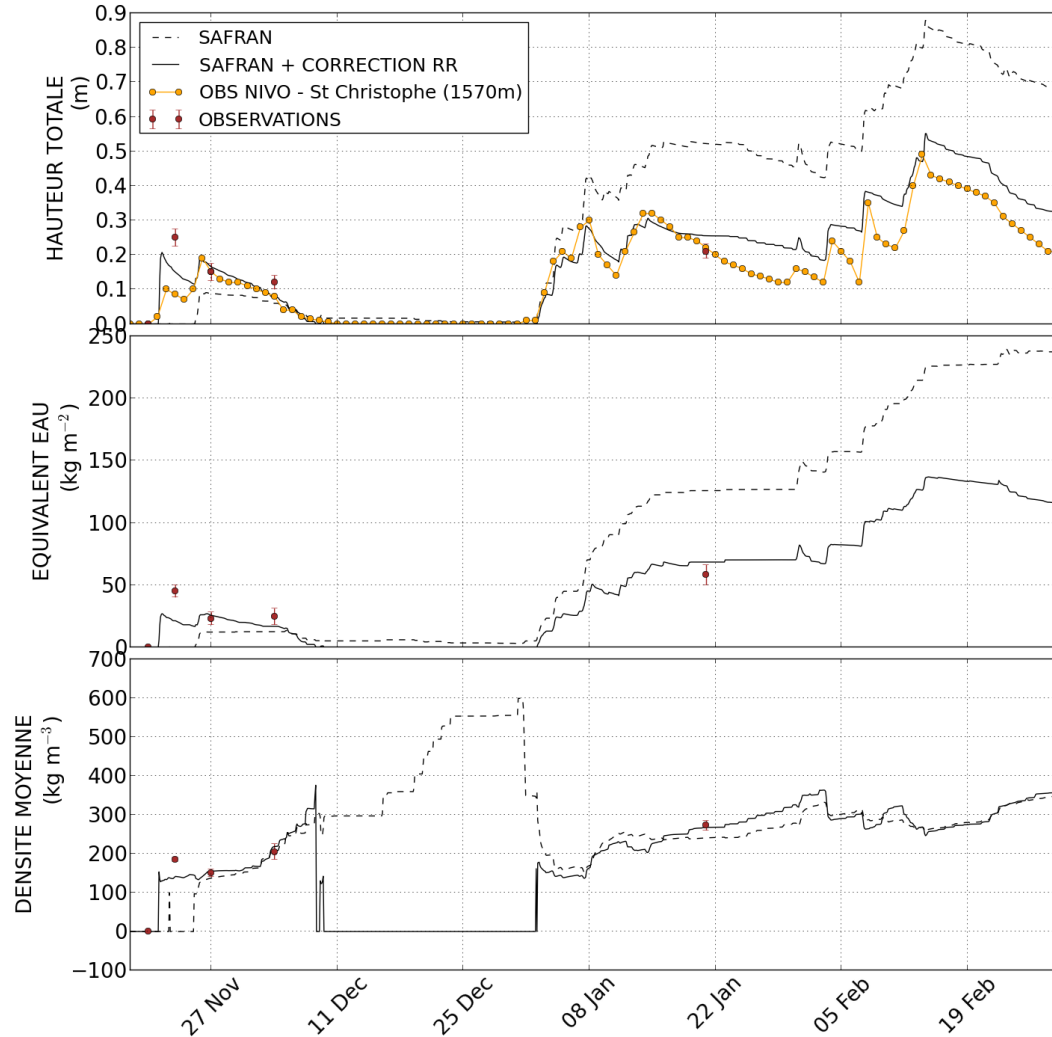


Modélisation de l'enneigement

Conditions de neige naturelle

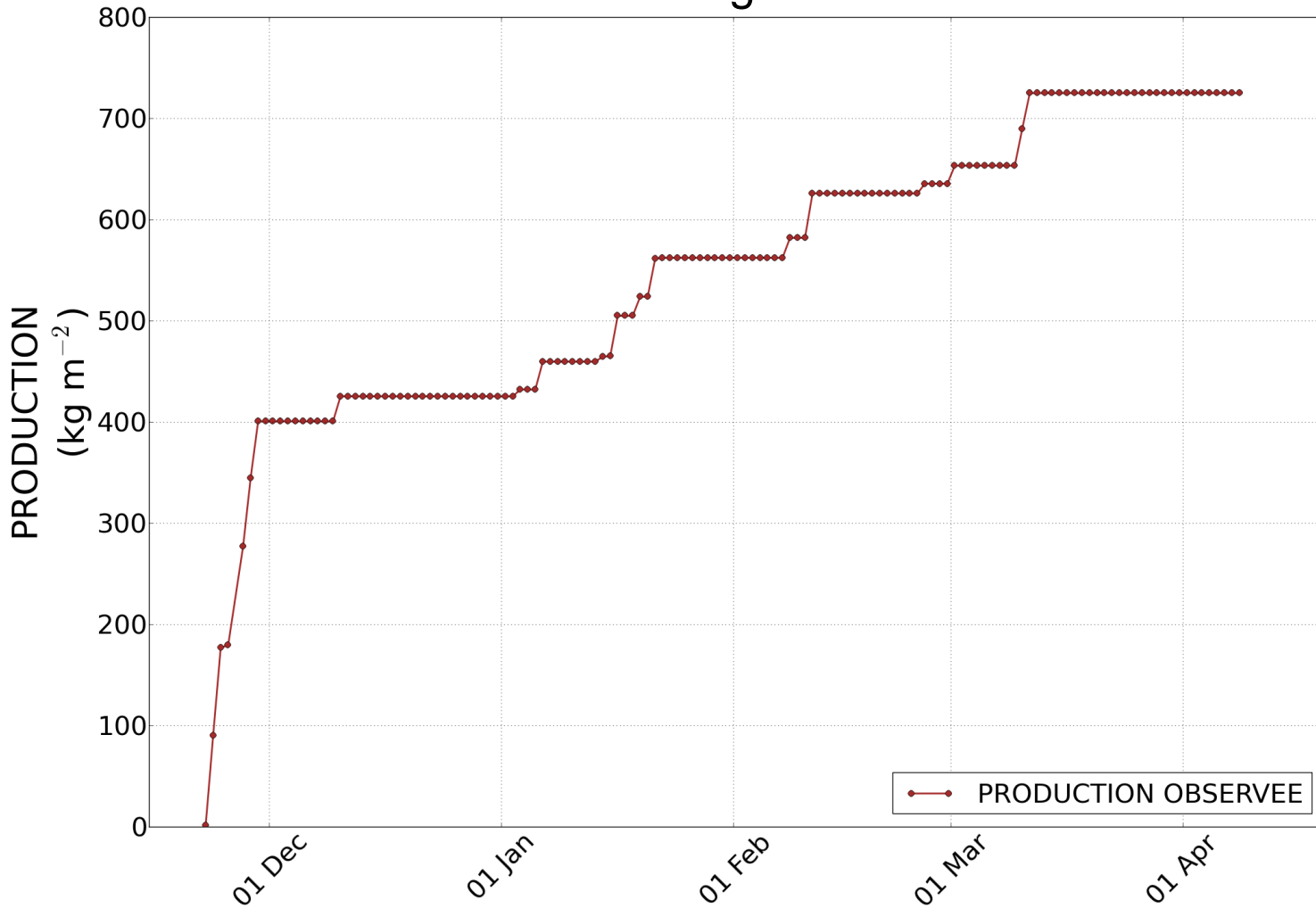
Période

21/11/2015 – 29/02/2016



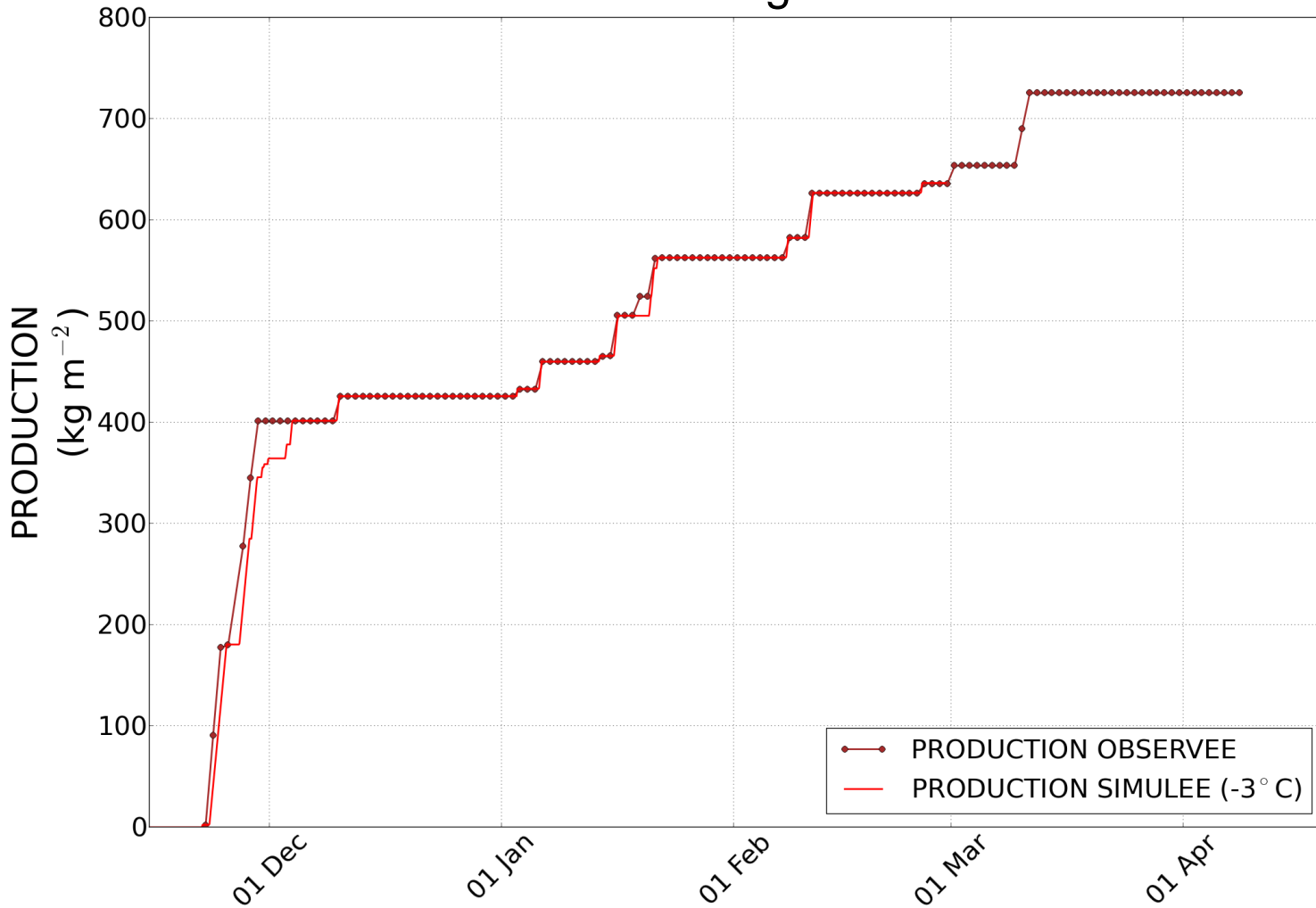
Modélisation de l'enneigement

Production de neige : Observations



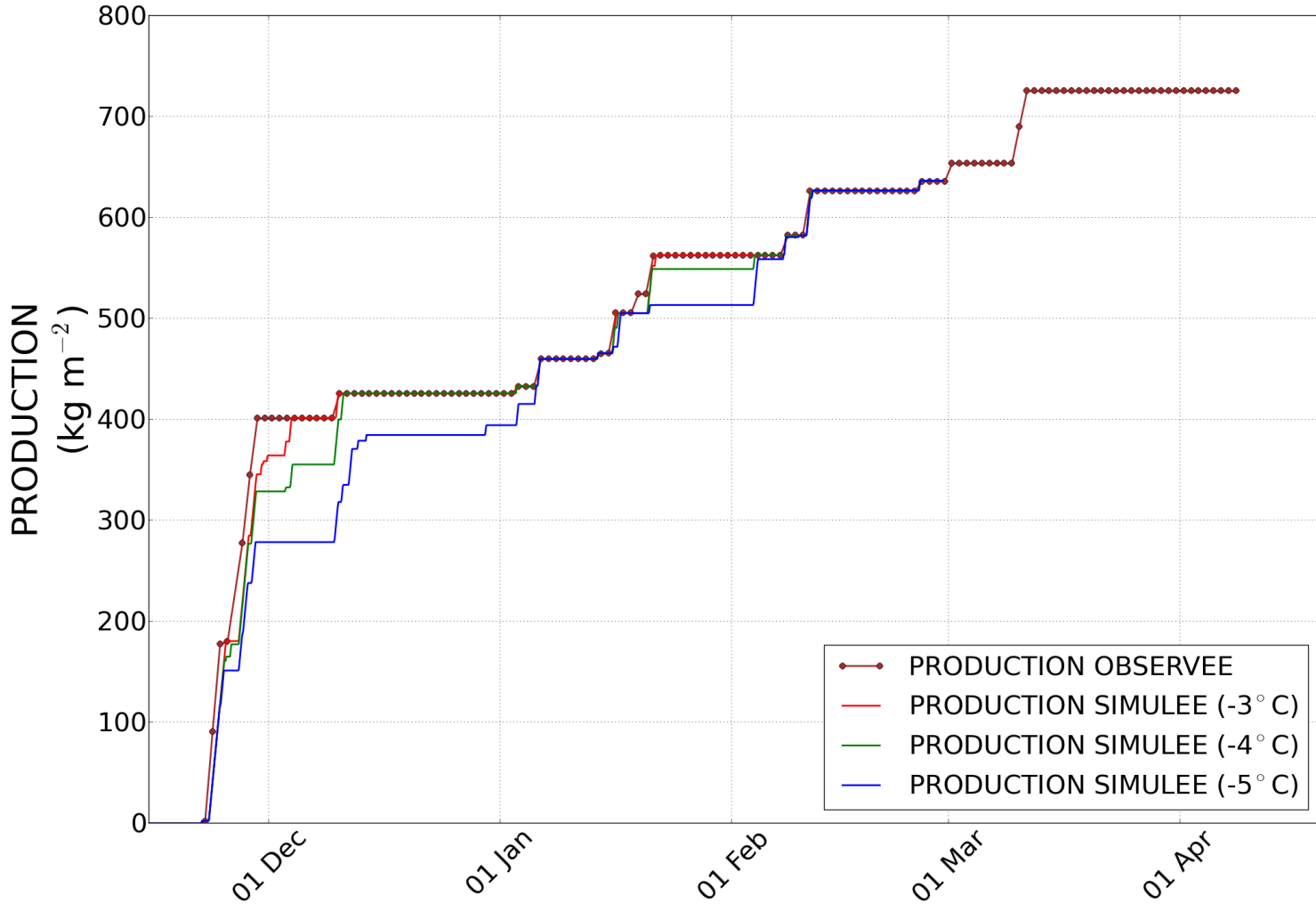
Modélisation de l'enneigement

Production de neige: Simulation



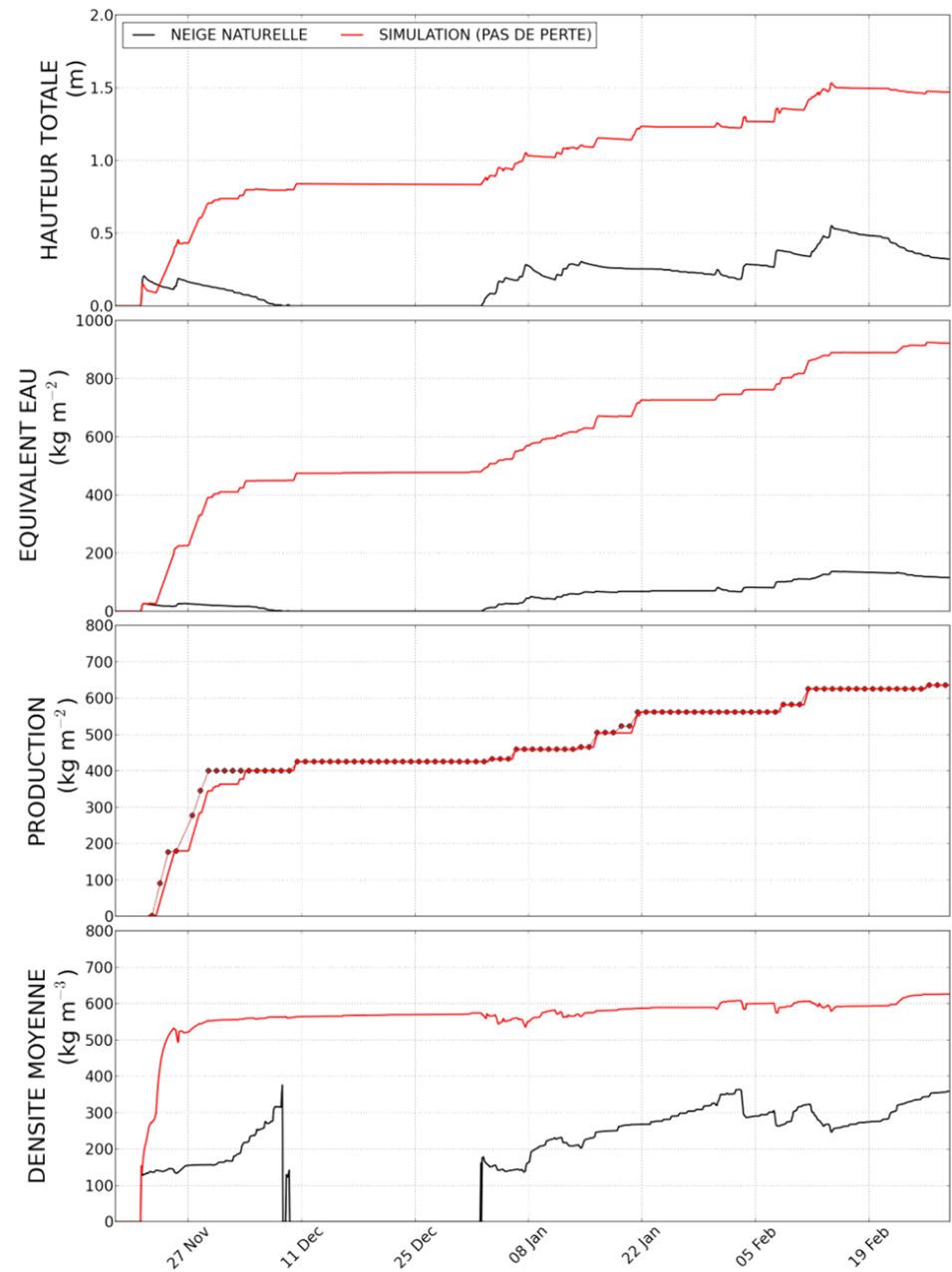
Modélisation de l'enneigement

Production de neige: Sensibilité au seuil de Tw



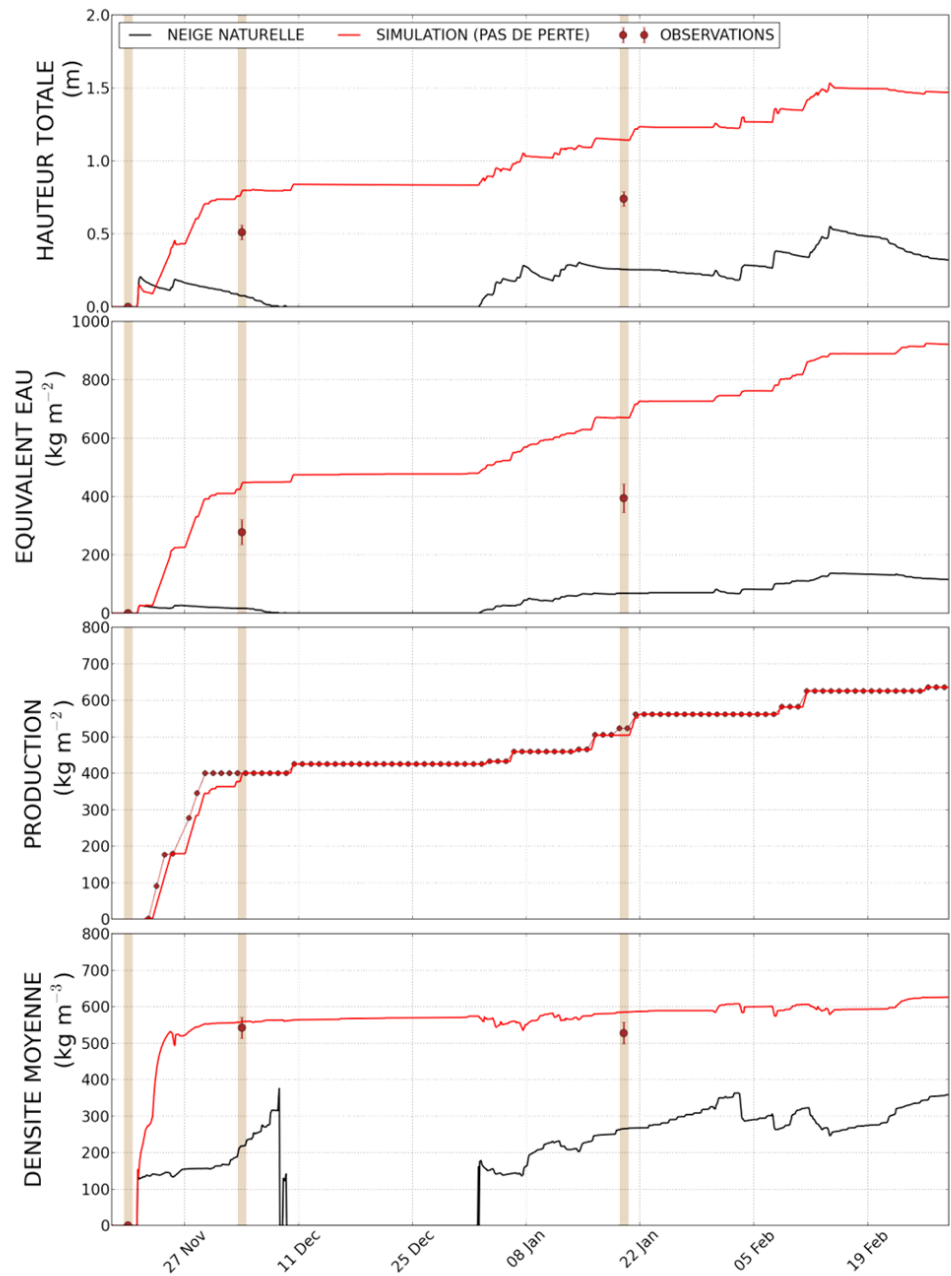
Modélisation de l'enneigement

Piste des Coolidge – 2Alpes



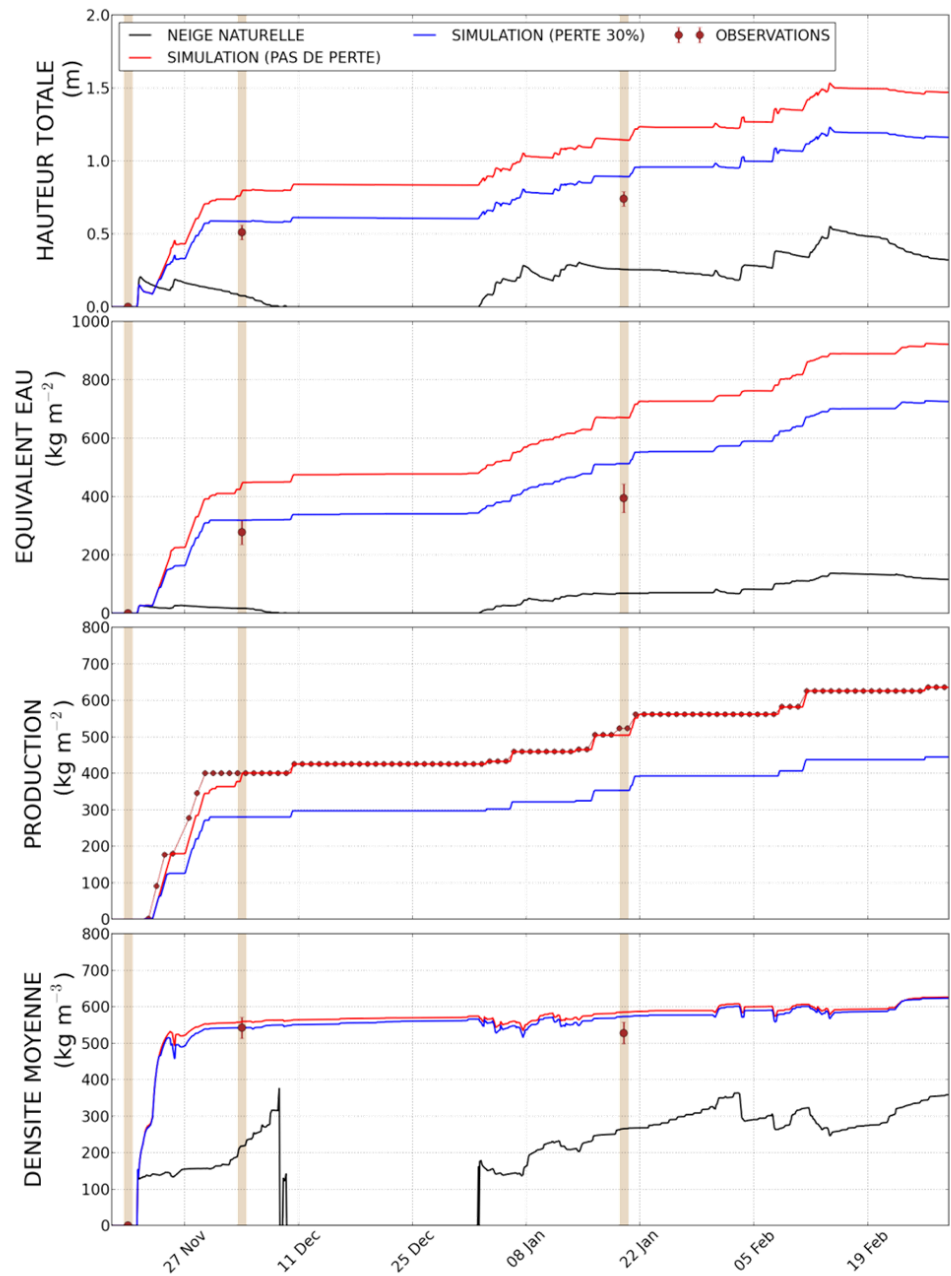
Modélisation de l'enneigement

Piste des Coolidge – 2Alpes



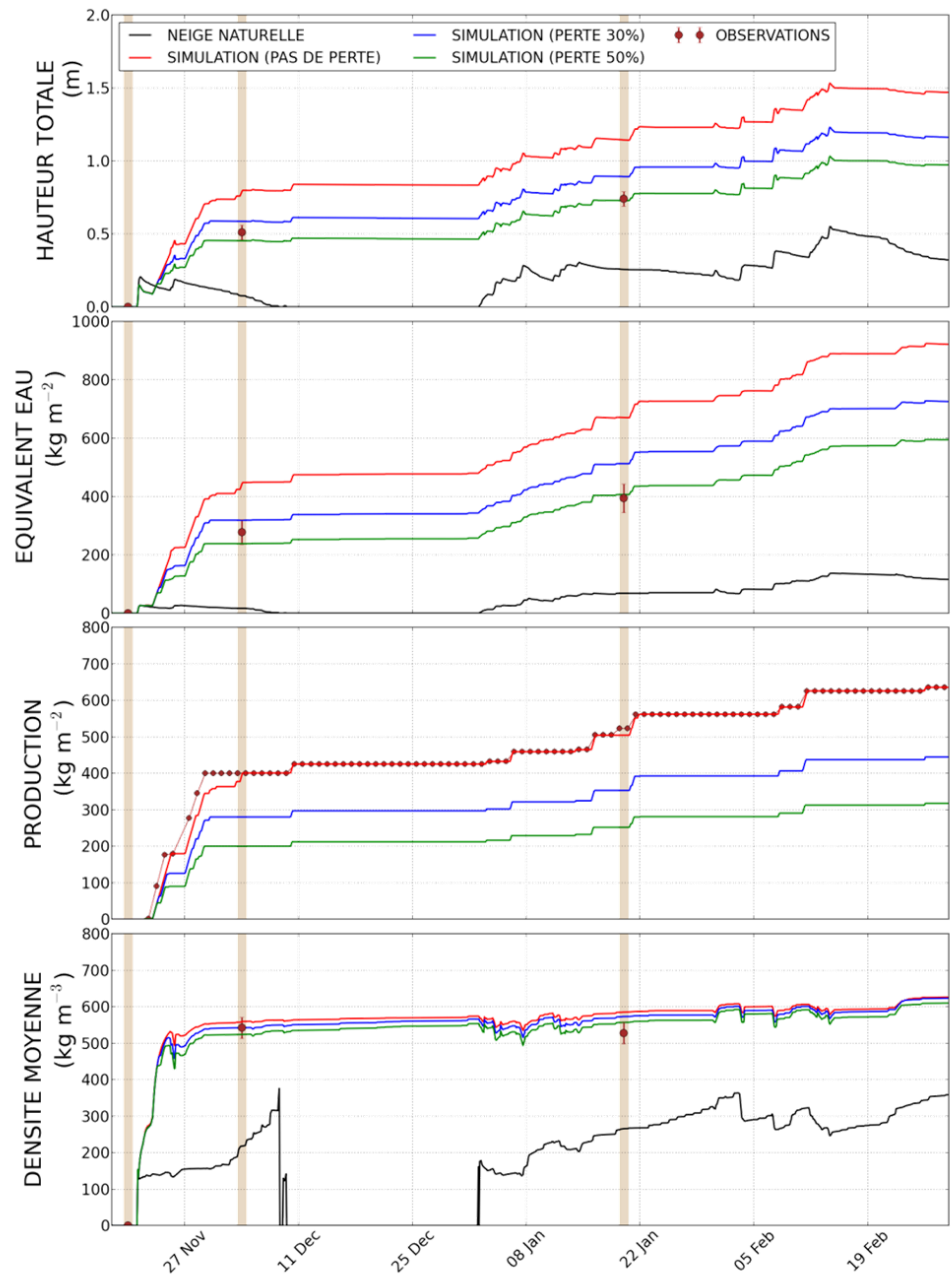
Modélisation de l'enneigement

Piste des Coolidge – 2Alpes



Modélisation de l'enneigement

Piste des Coolidge – 2Alpes



Erreur sur l'Equivalent en Eau

PERTE (%)	RMSE (kg m ⁻²)
NEIGE NATURELLE	186
0%	152
30%	63
40%	35
50%	20
60%	38

4 DECEMBRE	
PERTE (%)	Erreur (kg m ⁻²)
NEIGE NATURELLE	-260
0%	167
30%	42
40%	1
50%	-39
60%	-79

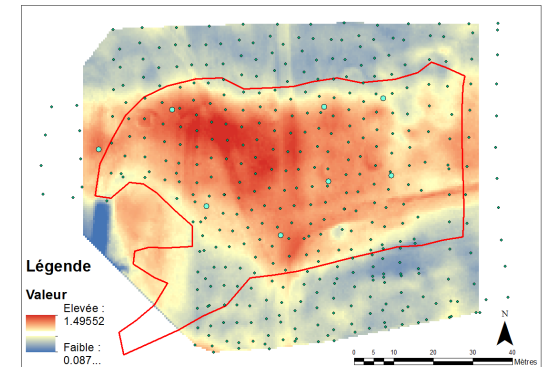
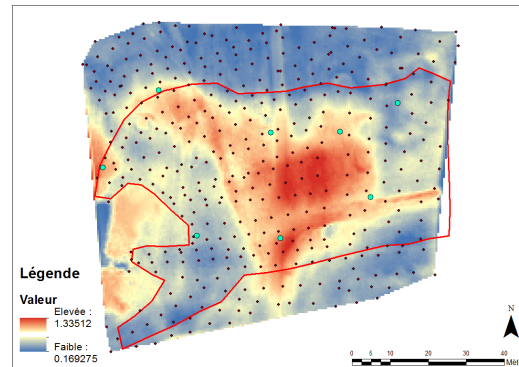
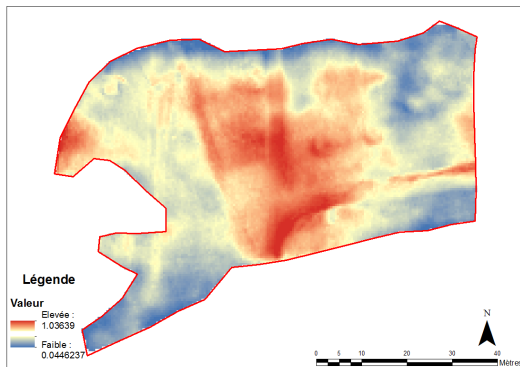
20 JANVIER	
PERTE (%)	Erreur (kg m ⁻²)
NEIGE NATURELLE	-325
0%	297
30%	134
40%	79
50%	24
60%	-30

Merci!

2016 – 01 – 20 (milieu)

2016 – 04 – 06 (droite)

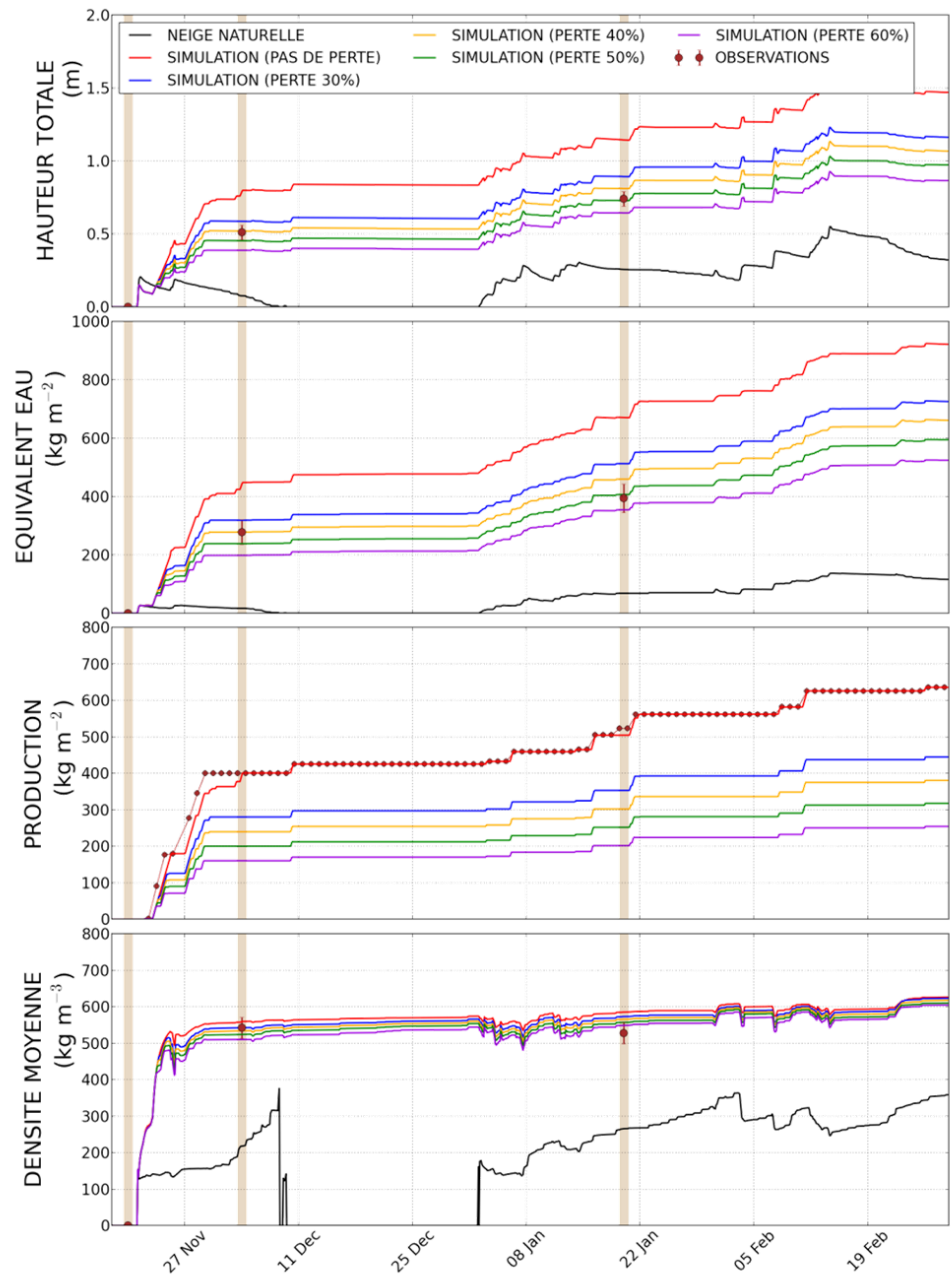
2015 – 12 – 04 (gauche)



Elements de complément

Modélisation de l'enneigement

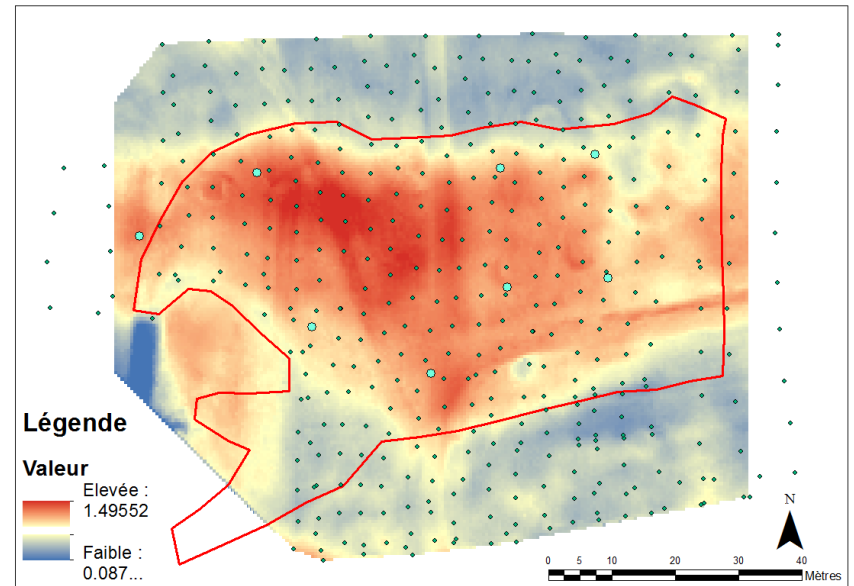
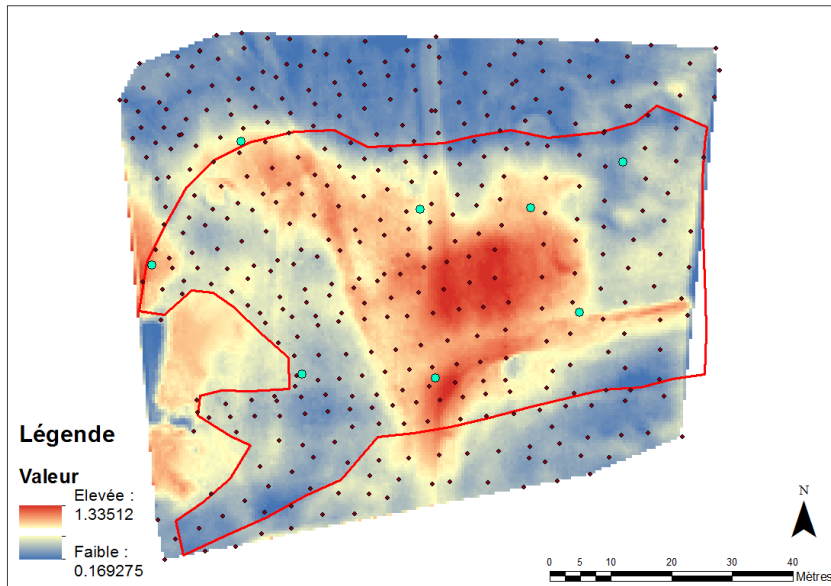
Piste des Coolidge – 2Alpes



Dates ultérieures

2016 – 01 – 20 (gauche)

2016 – 04 – 06 (droite)



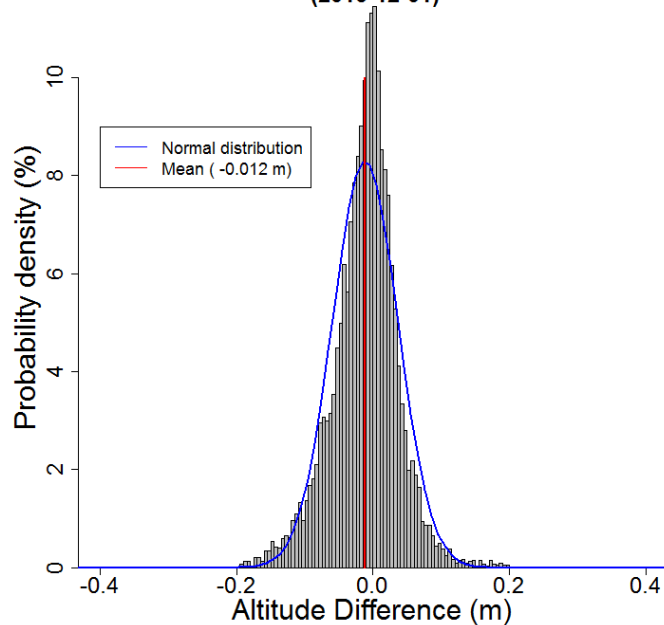
PICO #1.11 - Assessing the efficiency of snowmaking in ski resorts

Spandre P.^{1,2,*}, François H.¹, Thibert E.¹, Morin S.², George-Marcelpoil E.¹

¹ Université Grenoble Alpes, Irstea, ² Météo-France - CNRS, Grenoble, France

Evaluation of interpolation

Interpolation (GPS) vs. Laserscan measures
(2015-12-01)



Shared session with a laserscanner
(Surface 2012m²)

GPS points vs. Laserscan points

Mean difference	- 0.0046 m
Standard Dev.	0.055 m

Interpolation (Delaunay Triangulation) vs.

Laserscan points

Mean difference	- 0.012 m
Standard Dev.	0.048 m

=> Distribution of differences
assumed to follow
a normal law



Evaluation of interpolation

Propagation of uncertainties

(Normal distribution assumed)

Variability of laserscan measures

$$\sigma_{LS} = 0.031 \text{ m}$$

within a pixel (0.5 m x 0.5 m) => retained uncertainty on snow surface altitude

Uncertainty on **Snow Depth (SD)**

$$\sigma_{SD} = \sqrt{2} \times \sigma_{LS} = 0.044 \text{ m}$$

(Altitude difference)

Uncertainty on **Density (Rho)**

$$\sigma_{Rho} = 30 \text{ kg m}^{-3}$$

Uncertainty on **Equivalent water (SWE)**

$$\frac{\sigma_{SWE}}{SWE_{moy}} = \frac{\sigma_{Rho}}{Rho_{moy}} + \frac{\sigma_{SD}}{SD_{moy}}$$