Snow cover monitoring using combined FORMOSAT satellite imaging, *in situ sensing* oblique view ground-based pictures and snow drills

(East Loven glacier, Spitsbergen, Svalbard)

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Summary

Introduction

1. Field localization
2. Flood event of september 2008
3. In situ image data collection
4. In situ image geometric correction
5. Snow and ice melt quantification

Conclusion

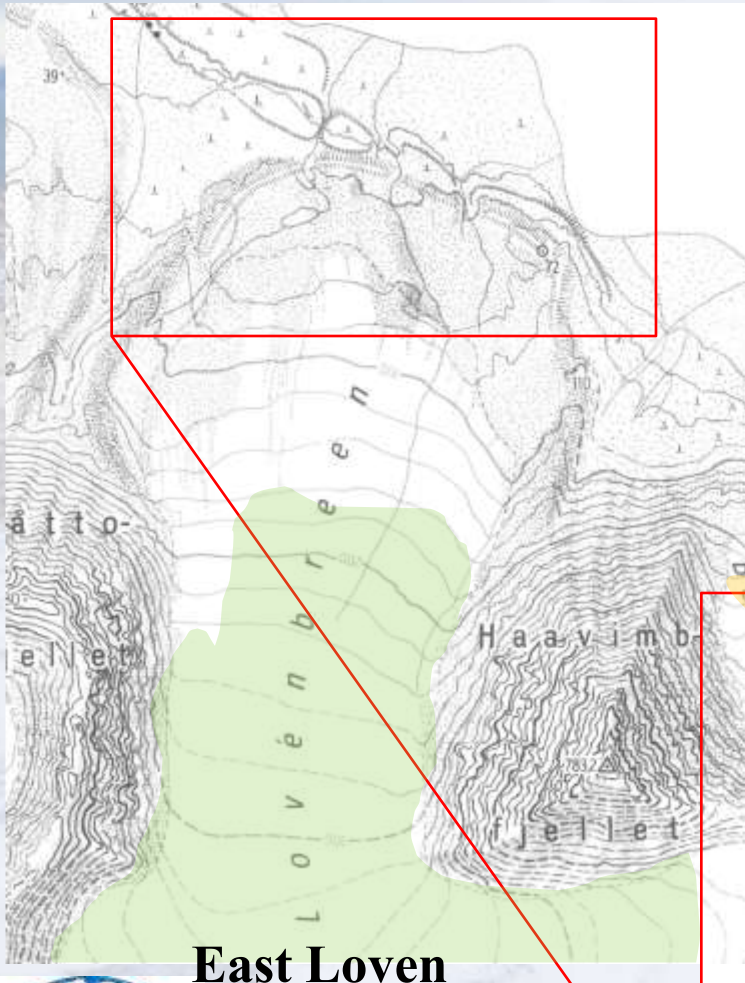
In the frame of the Hydro-Sensor-FlOWS program funded by the French National Research Agency and the French Polar Institute (IPY 16), the East Loven glacier, located in Spitsbergen (78°N, 12°E, Norway) has been closely monitored during the last 4 years (2007 to 2010) in order to analyze at the basin scale (10 km^2) and at various time scales (hour, day, month, year) the ice and snow mass-balance and their direct and indirect hydrological consequences.

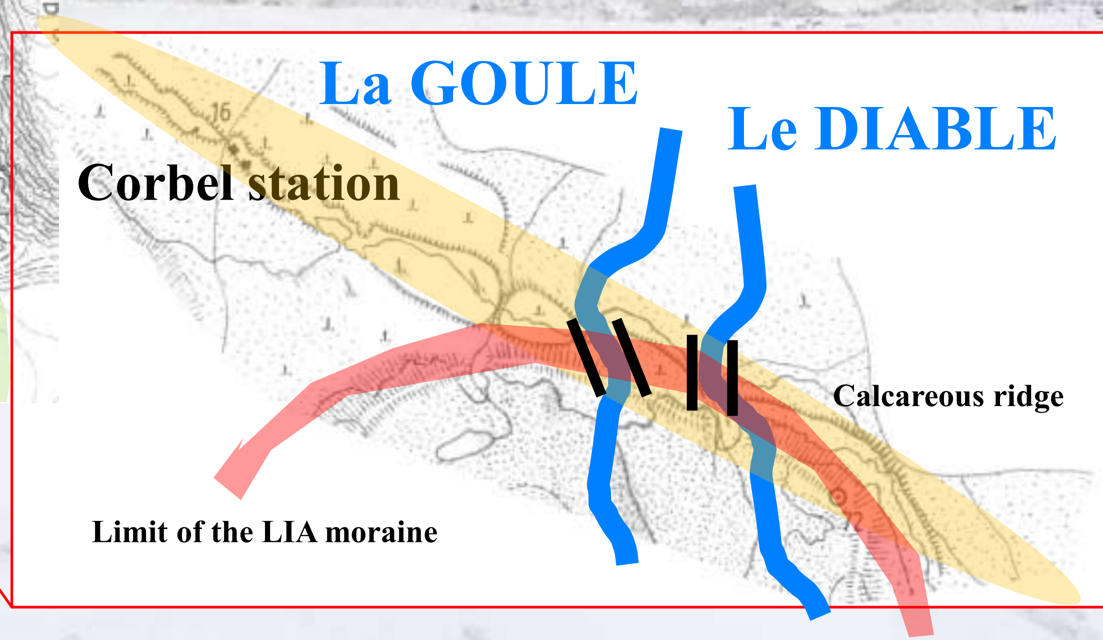
For obvious cost reasons as well as due to poor weather/cloudy conditions, daily satellite imaging coverage is not always accessible: eleven images are acquired each year but only two monthly FORMOSAT data sets have been selected as representative of general snow cover.

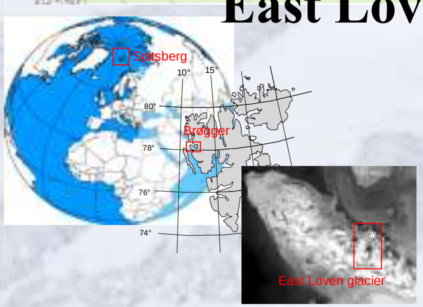
Nevertheless, fast events appear as significant in the ice and snow budget while being ignored by satellite based studies since the slower sampling rate is unable to observe such fast events. In this project, satellite imagery is complemented with a series of ground based autonomous automated high resolution digital cameras.

An example of the complementarity of database was presented about a flood period in september 2007.

Field localization







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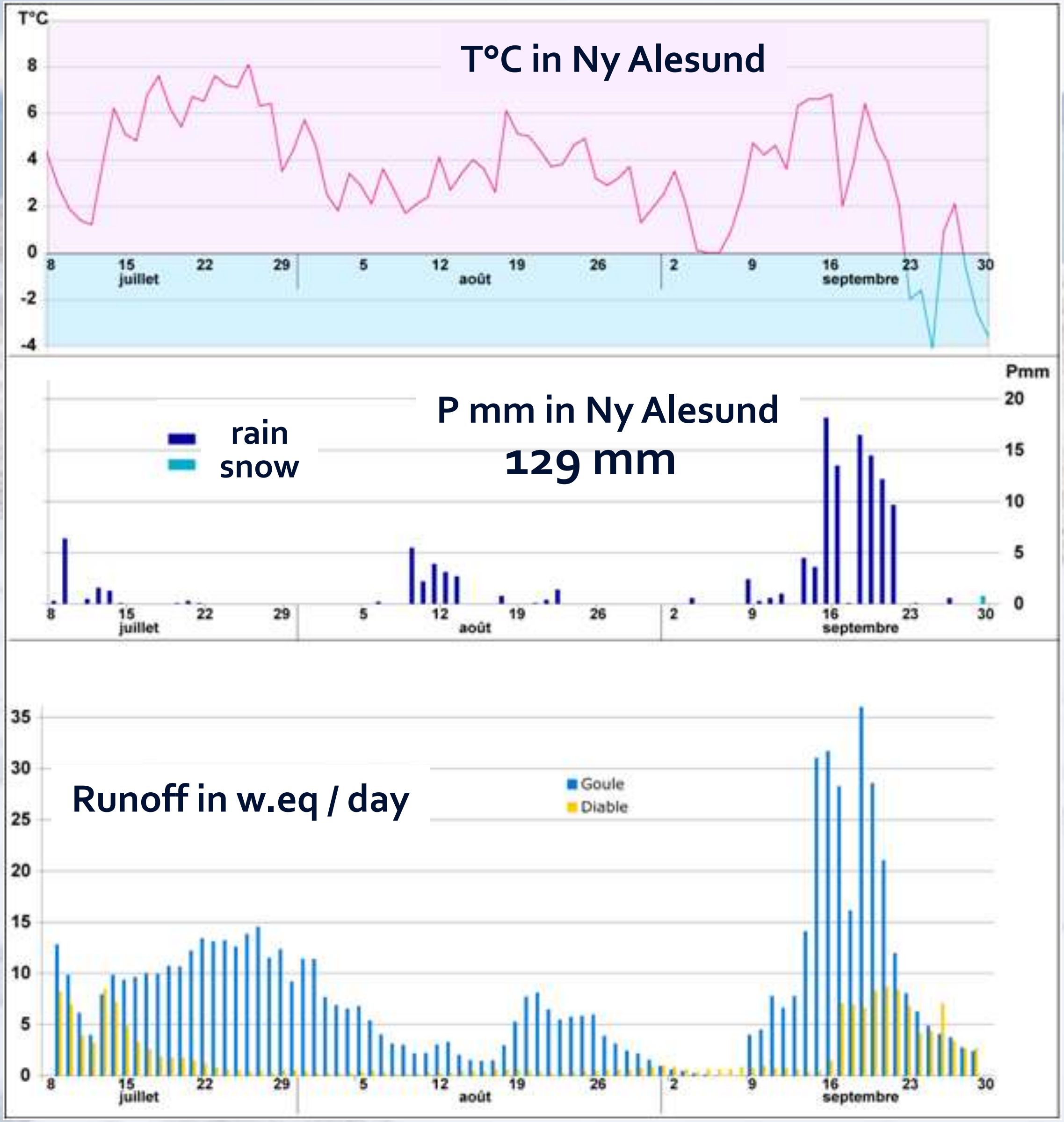
Flood period at the end of 2008 Summer



hydrological summer 2008

Total precipitation

129 mm

Runoff in w.eq

Goule	680 mm
Diable	174 mm

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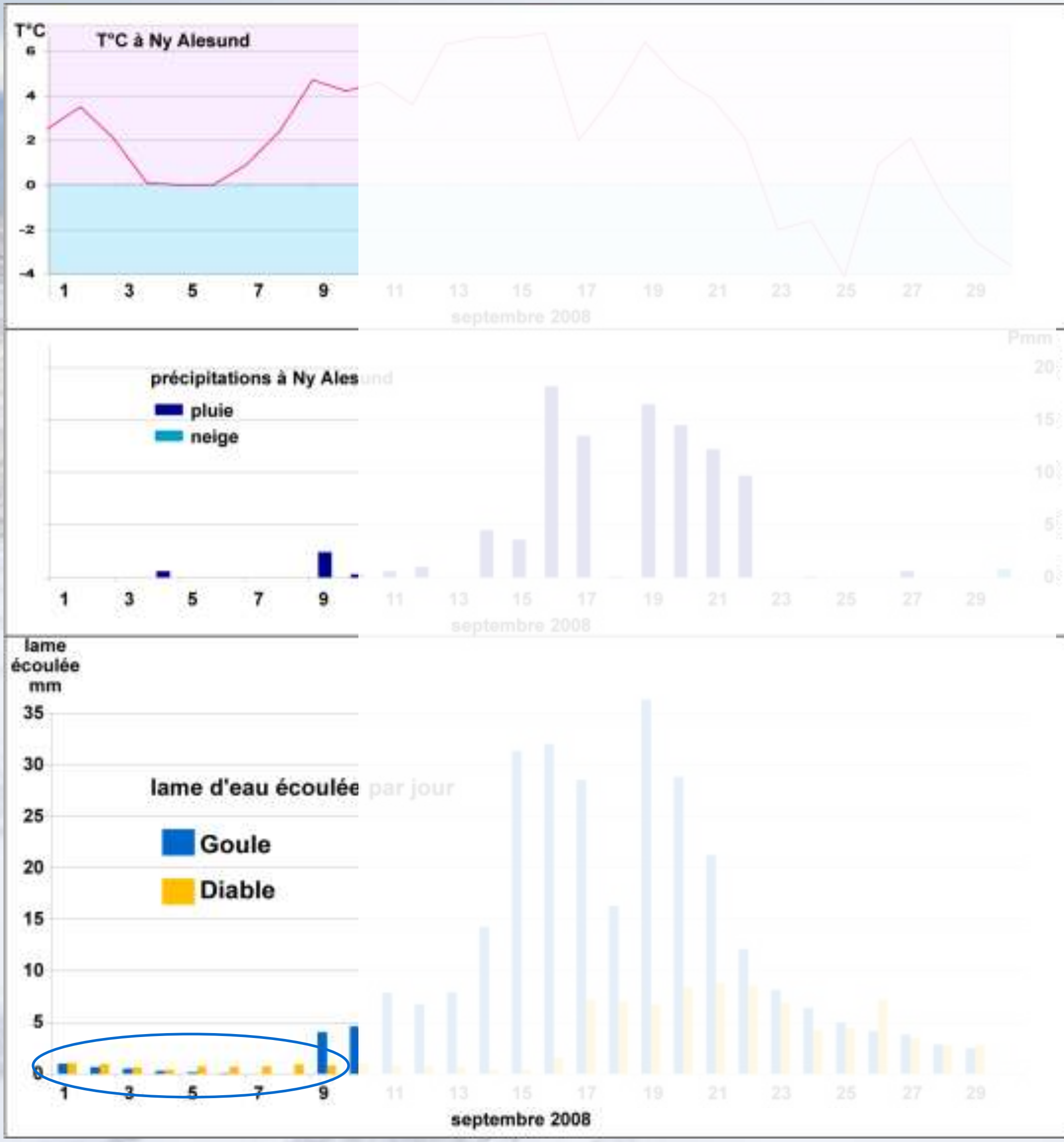
Flood period at the end of 2008 Summer



1[st] week of September: cold, no water in rivers → it seems that it is the beginning of winter

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Flood period at the end of 2008 Summer

2^{d} week, sudden increase of T and 10% of the yearly precipitation

Due to the rain, snow and ice melt on the glacier (flood water in the Goule river) while the moraine absorbs the rain like a sponge (Diable river stays constant)

The rain stops one day: immediate response of the Goule river. Then a new rain event gives again flood water in the Goule. The moraine is than saturated and the Diable begins to grow up.

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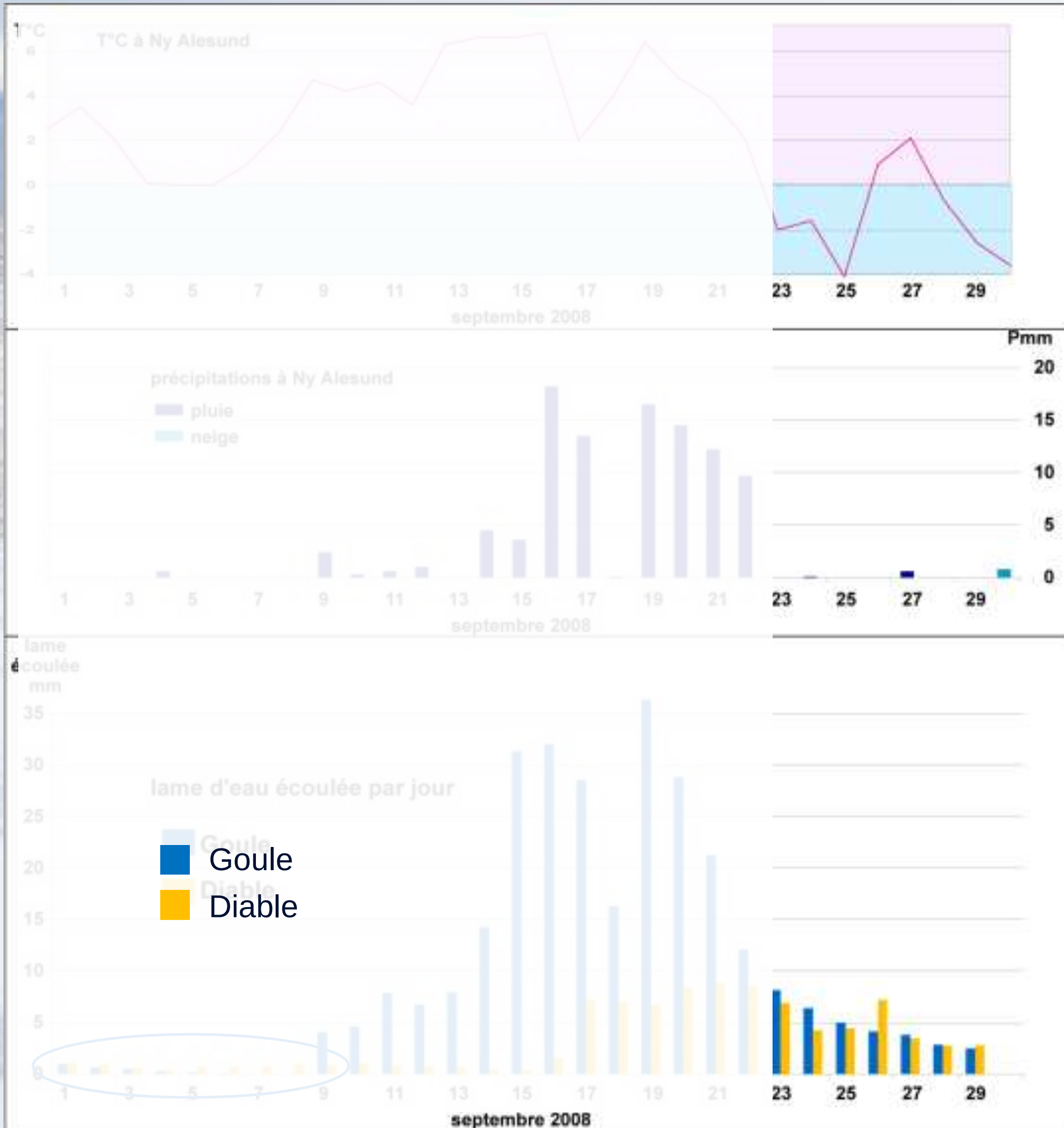
Flood period at the end of 2008 Summer



The last week, T decreases and the rain stops. It snows. The fall in level is slow, sustained by the sub-glacial runoff.

BUDGET

76% of summer precipitation (100 mm)

40 % of the summer runoff (260 mm)

160 mm of melting of snow and ice

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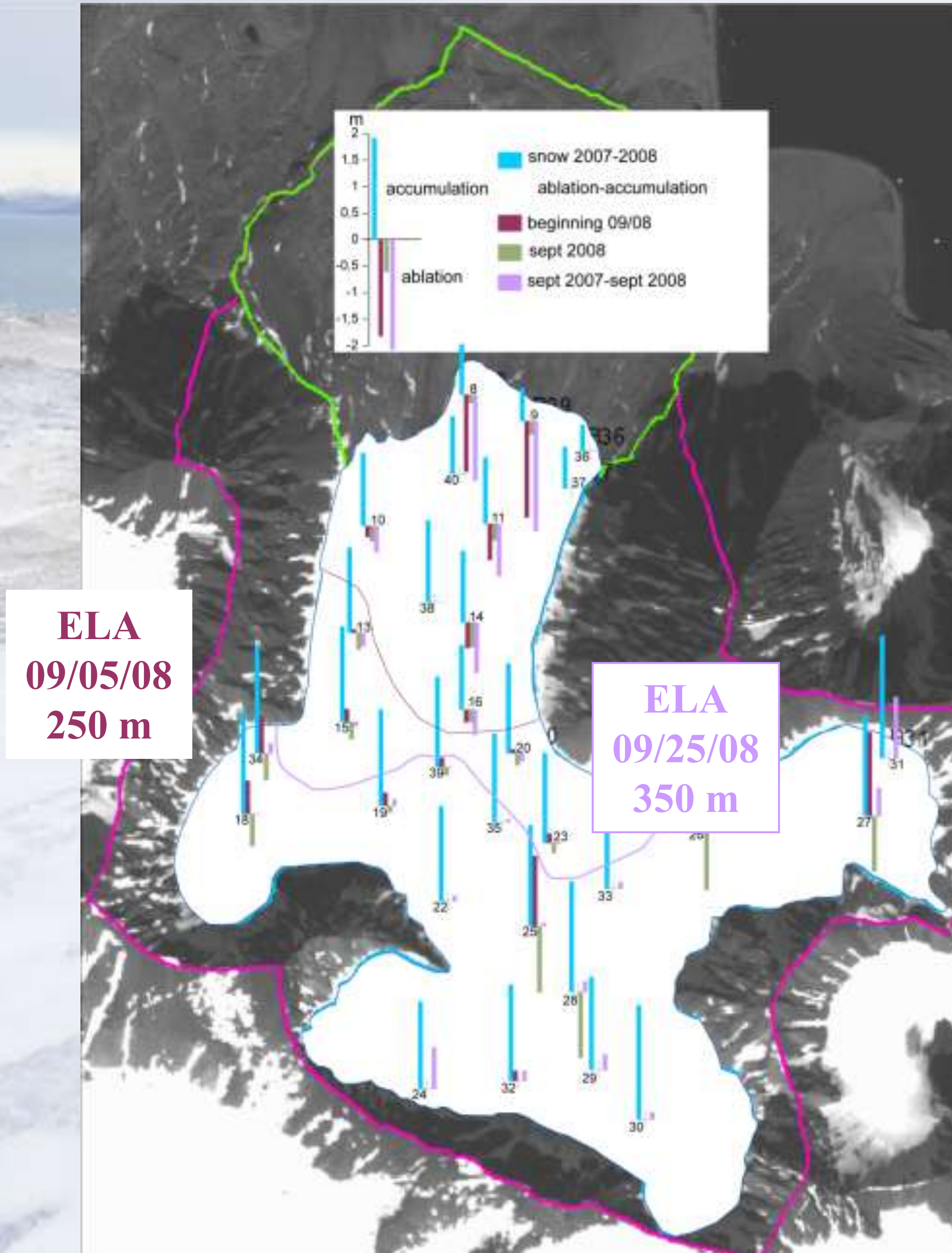
Ablation *vs* Accumulation



Snow high and quality field measures

During that flood period, the equilibrium line (ELA) of the glacier growed up from 250m to 350m.

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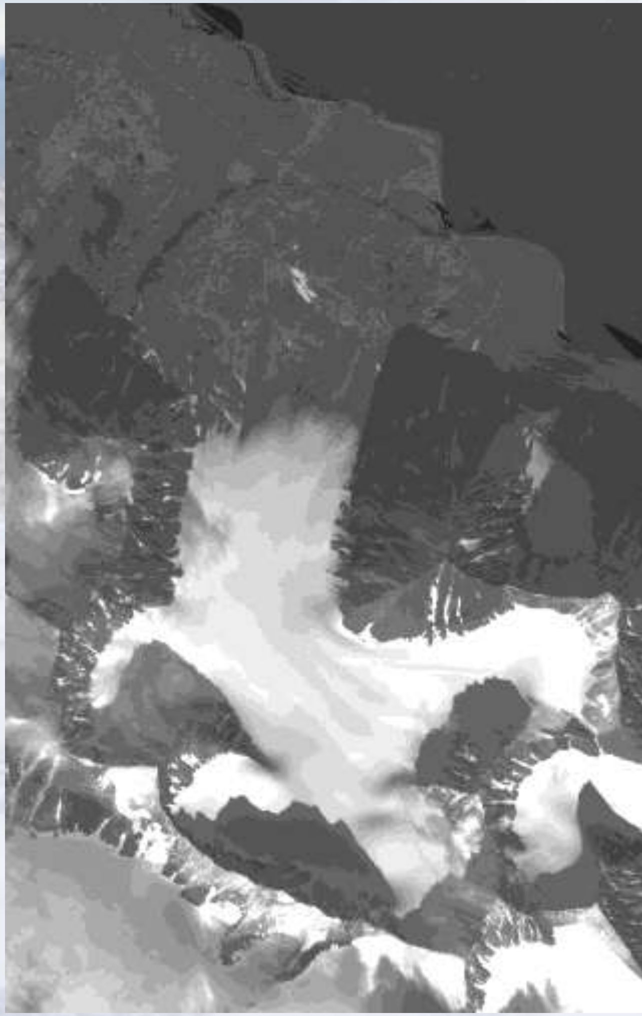
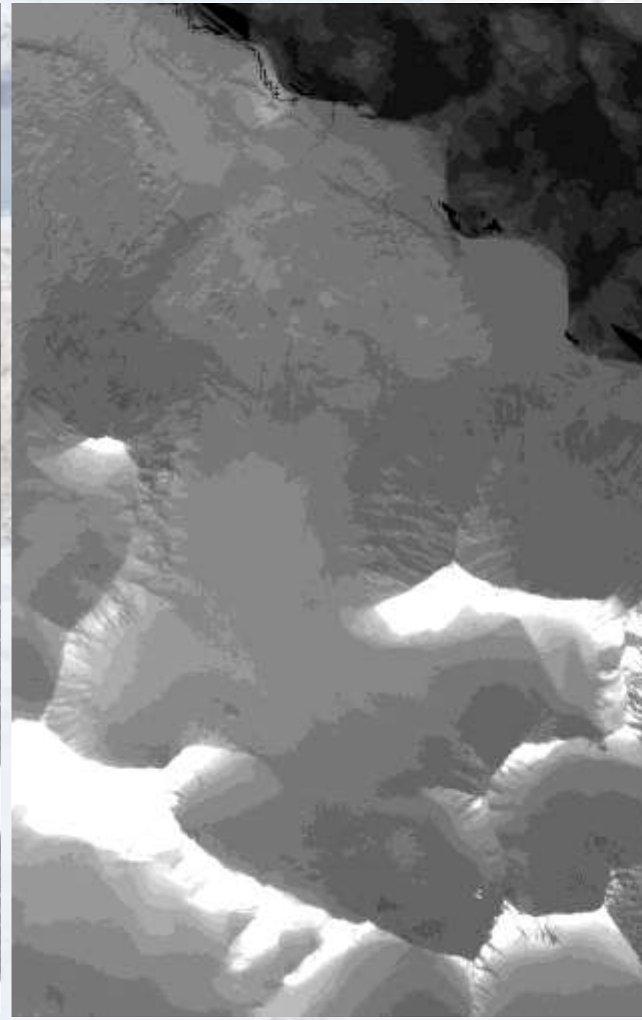
15th of august



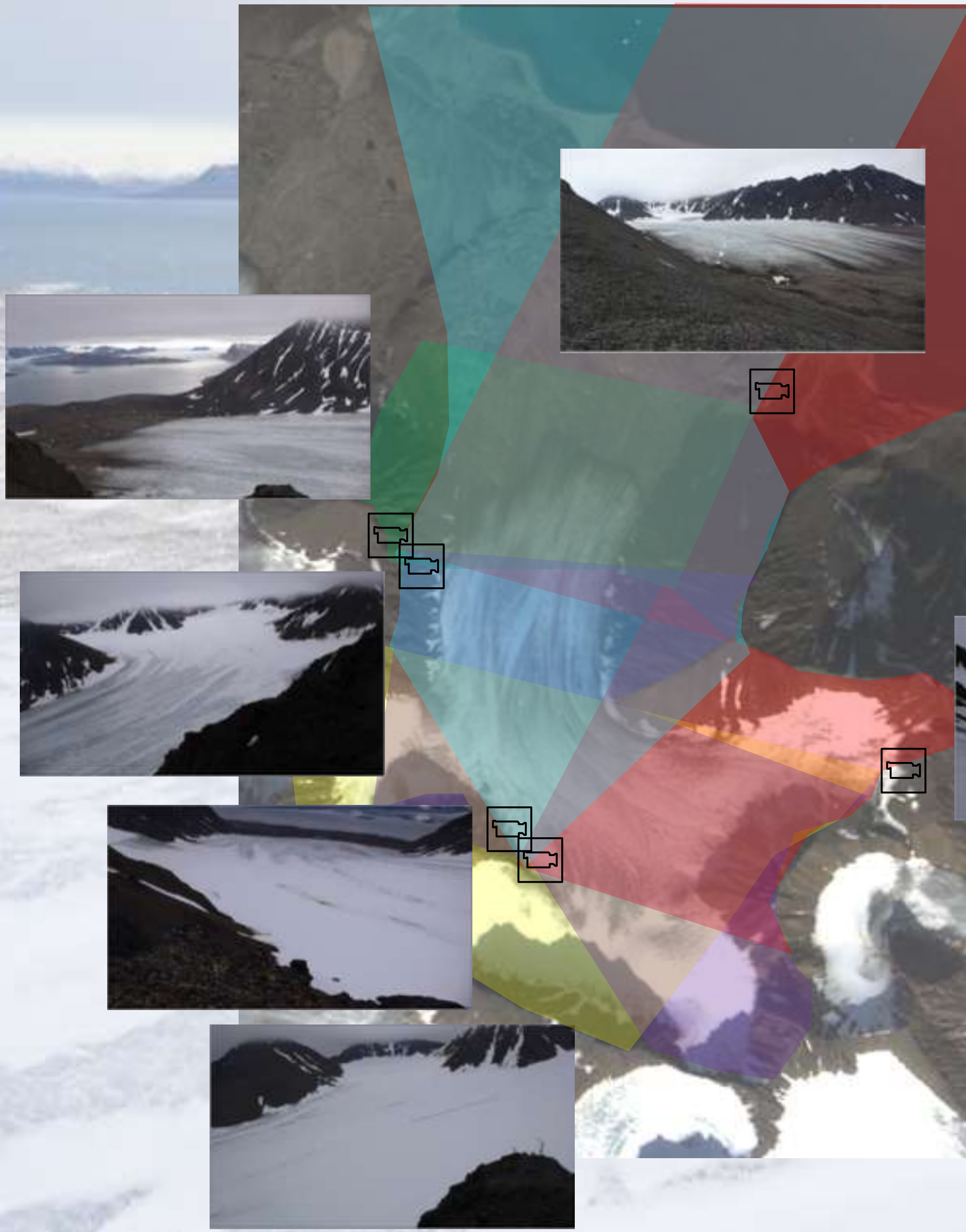
30th of september



FORMOSAT specifications

Products	B&W : 2 m Color: 2 m (pansharpened) MS (R, V, B, PIR) : 8 m
Spectral bands	P : 0,45 – 0,90 µm B1 : 0,45 – 0,52 µm (blue) B2 : 0,52 – 0,60 µm (green) B3 : 0,63 – 0,69 µm (red) B4 : 0,76 – 0,90 µm (NIR)
Coverage	24 km x 24 km
Repetiivity	daily
Angle	lateral &front-back: +/- 45°
Programmation	Yes
Image dynamics	8 bits/pixel
Image size (1A level)	MS : 35 MB Pan : 137 MB

Only two Formosat images are available around this flood event (August 15th and September 30th) … showing the glacier totally cover of snow



Six digital cameras are positioned around the glacier basin, providing complete glacier coverage

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in situ acquisition – 3 images per day…

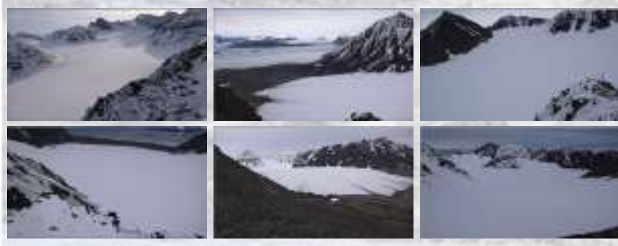
… weather conditions + electronics: only a fraction of the available data is usable !

08/ 15/ 2008

09/ 03/ 2008

09/ 04/ 2008

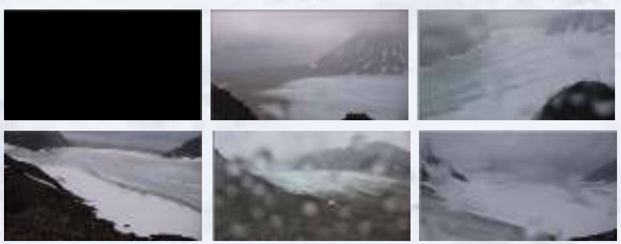
09 / 08/ 2008



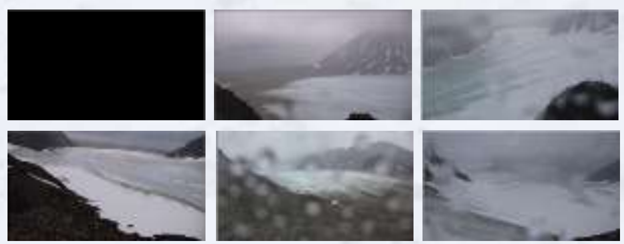
09 / 10/ 2008

09 / 13/ 2008

09 / 15/ 2008

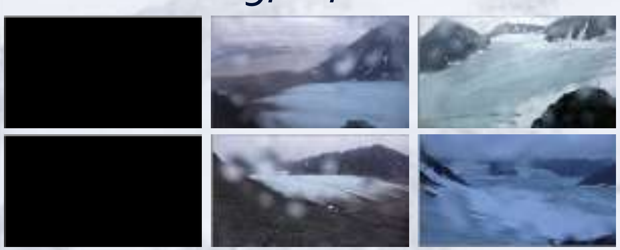


09/ 17/ 2008



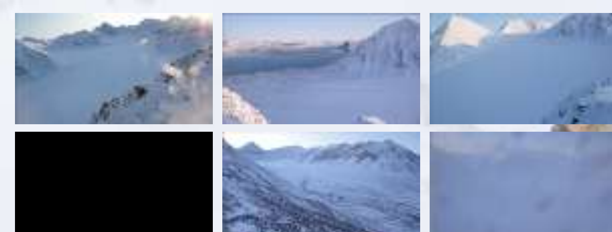
09/ 19/ 2008

09/20/ 2008



09/30/ 2008

10/03/ 2008



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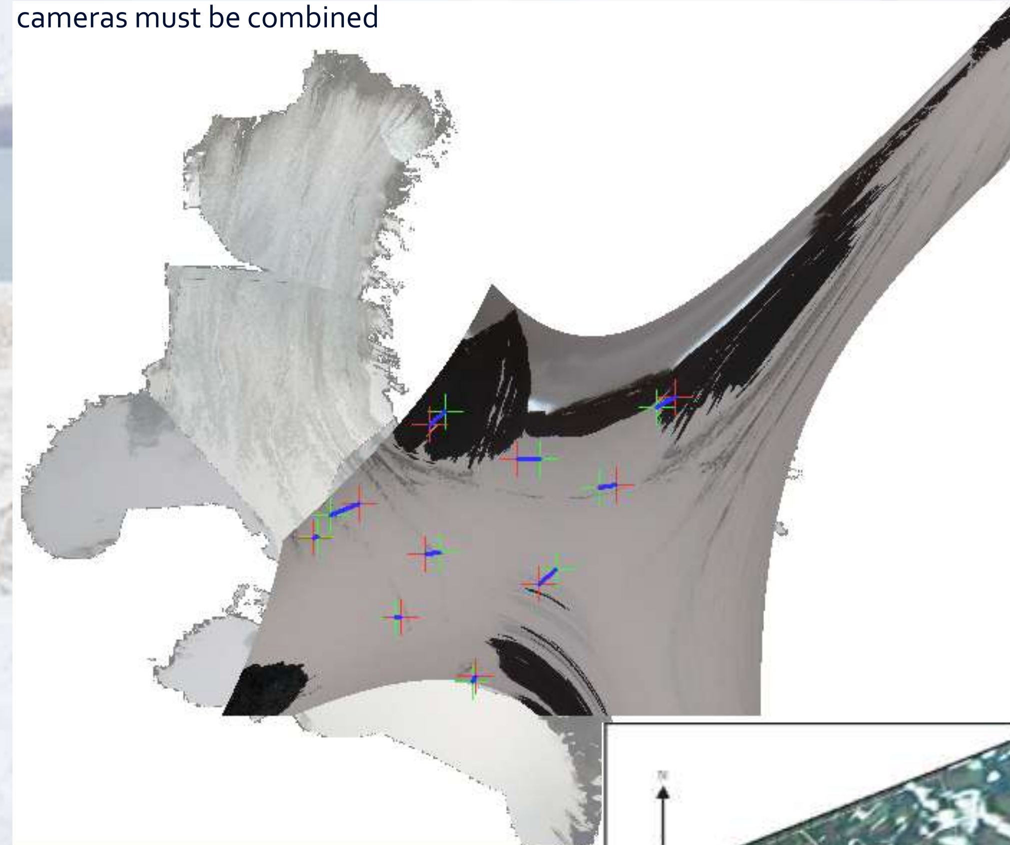
Geometrical orthorectification models are not appropriate due to the tangential views, especially since several images taken from different cameras must be combined

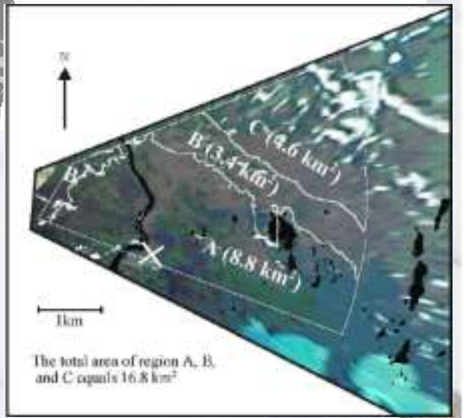


Oblique views provide a qualitative information on daily glacier evolution.

In order to be used on a map, these images must be projected.

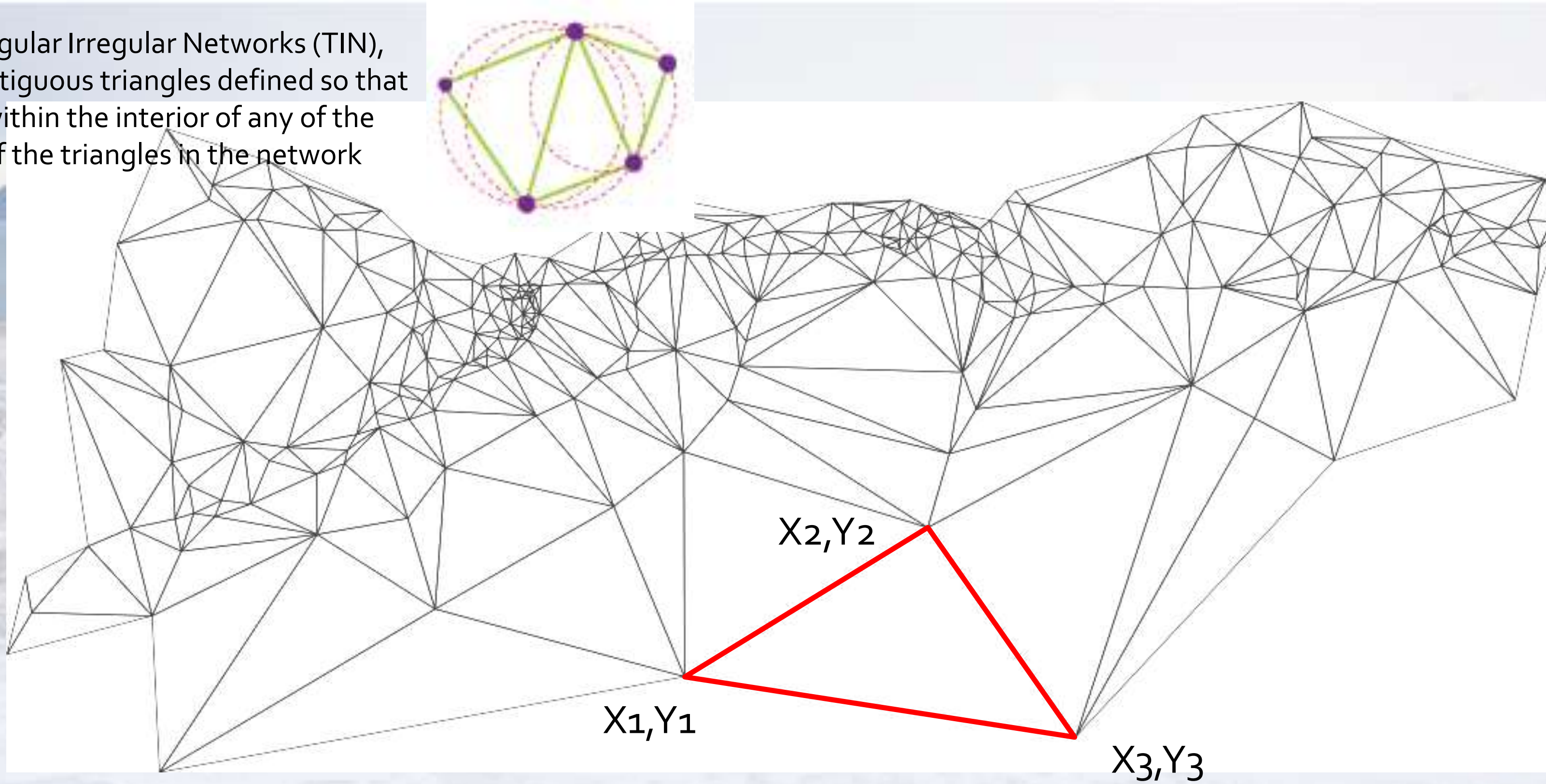
Classical calibration models fail due to several constraints.

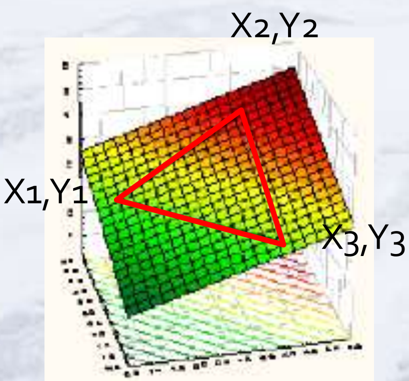
The Delaunay triangulation (rubber sheeting) model is adapted if enough reference points are available for a dense initial triangulation.



Hinkler, J. , Pedersen, S. B. , Rasch, M. and Hansen, B. U.(2002) 'Automatic snow cover monitoring at high temporal and spatial resolution, using images taken by a standard digital camera', International Journal of Remote Sensing, 23: 21, 4669 — 4682

Delaunay Triangular Irregular Networks (TIN), network of contiguous triangles defined so that no vertex lies within the interior of any of the circumcircles of the triangles in the network





$$X_{est}=a_1X+b_1Y+\varepsilon_1$$
$$Y_{est}=a_2X+b_2Y+\varepsilon_2$$

Latitudes and longitudes are estimated from regression plane equations or a spline surface.

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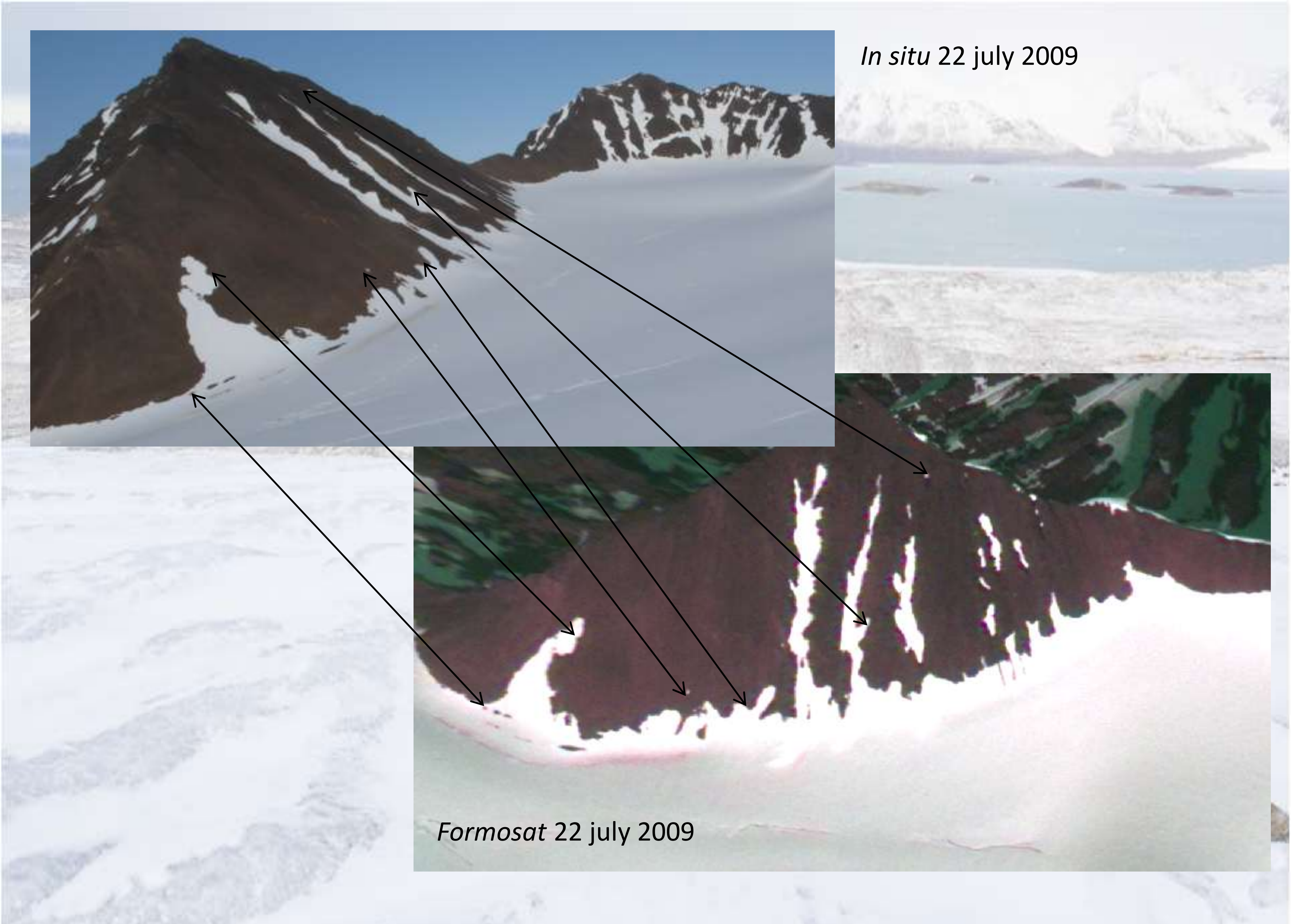


In situ 22 july 2009
Formosat 22 july 2009

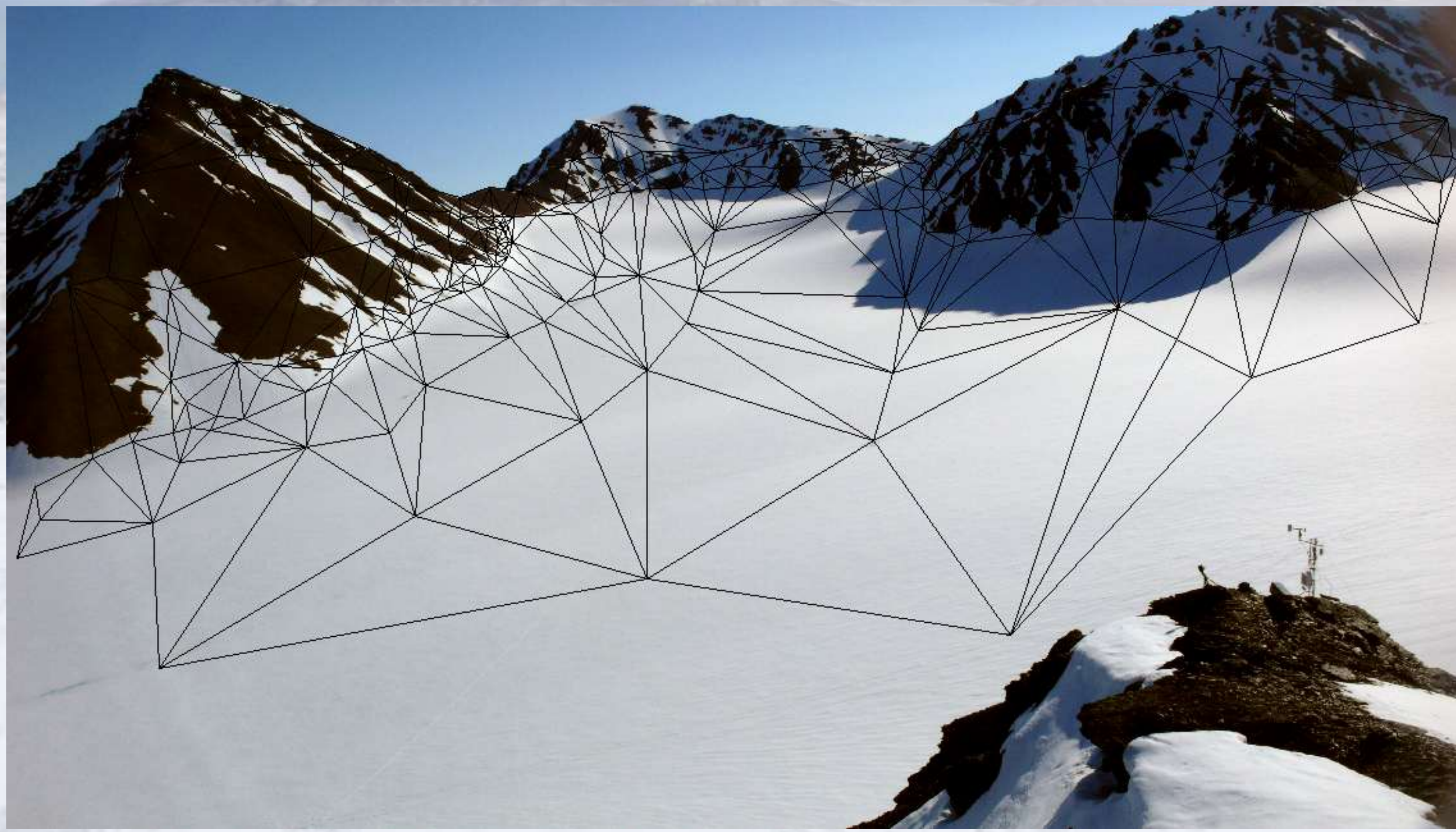
Reference points are defined on the glacier using flags

Detail

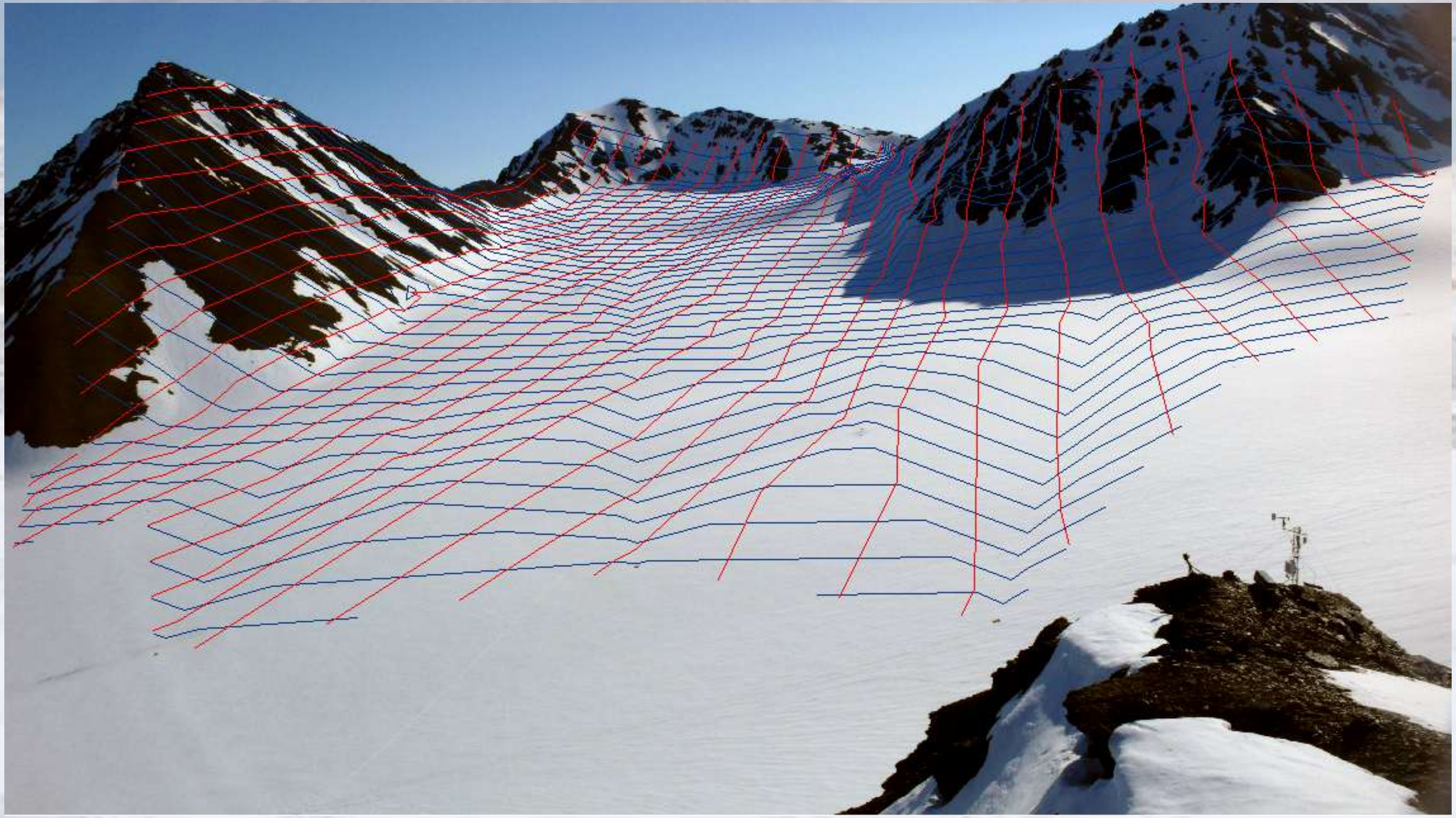
No reference control point on the glacier

Localisation GPS des points

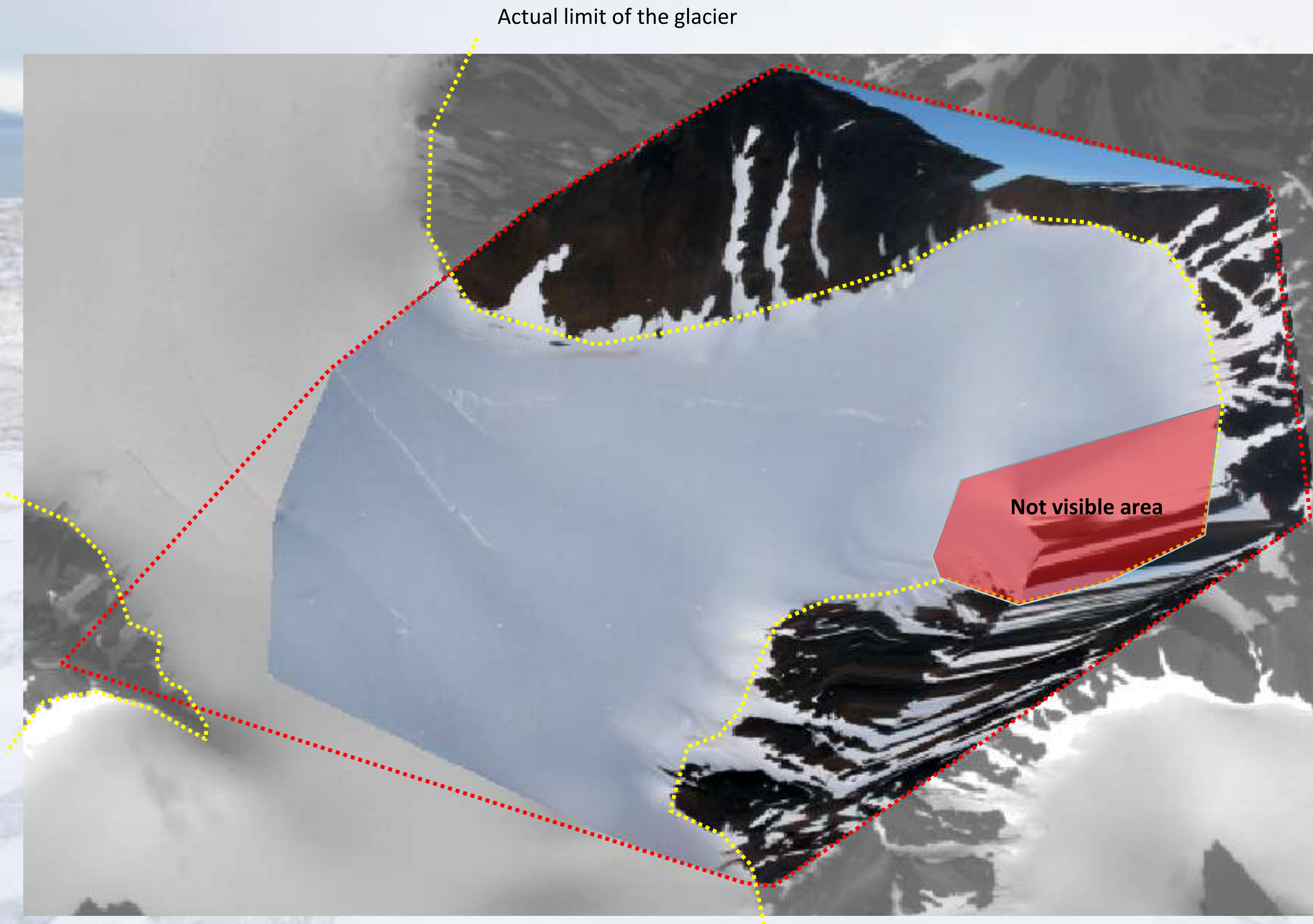
Ground Control Point



Delaunay interpolation triangles (TIN)

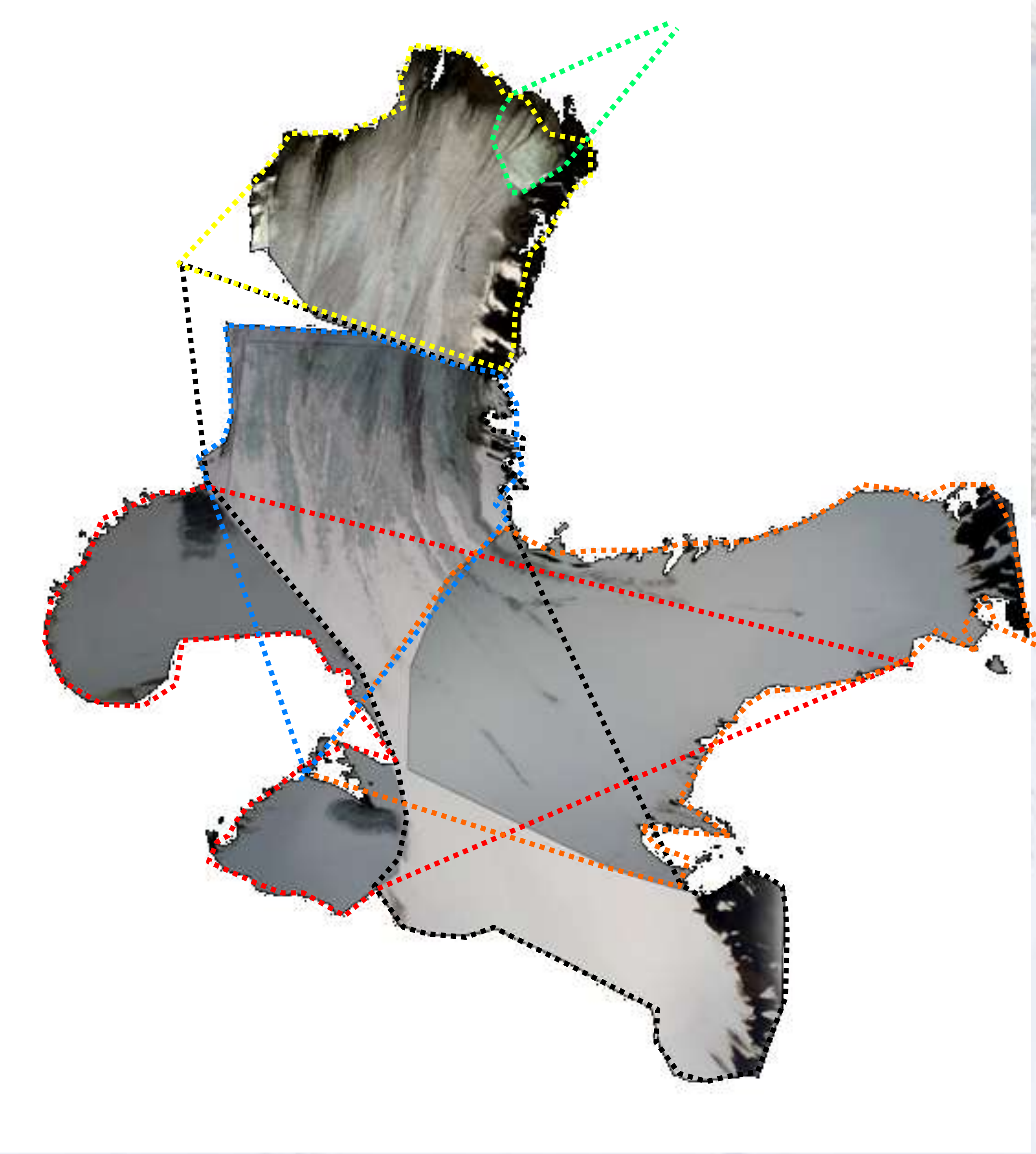


Latitude and longitude simulation



Final rectification

Combination of images provided by different cameras (over 98 % of the glacier surface is mapped)



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Geometrical models for each camera are only valid as long as images are acquired in the exact same conditions.

Technical constraints associated with the instruments and harsh environmental conditions require replacing the camera several times.

Camera replacement necessarily induces some frame change/motion.

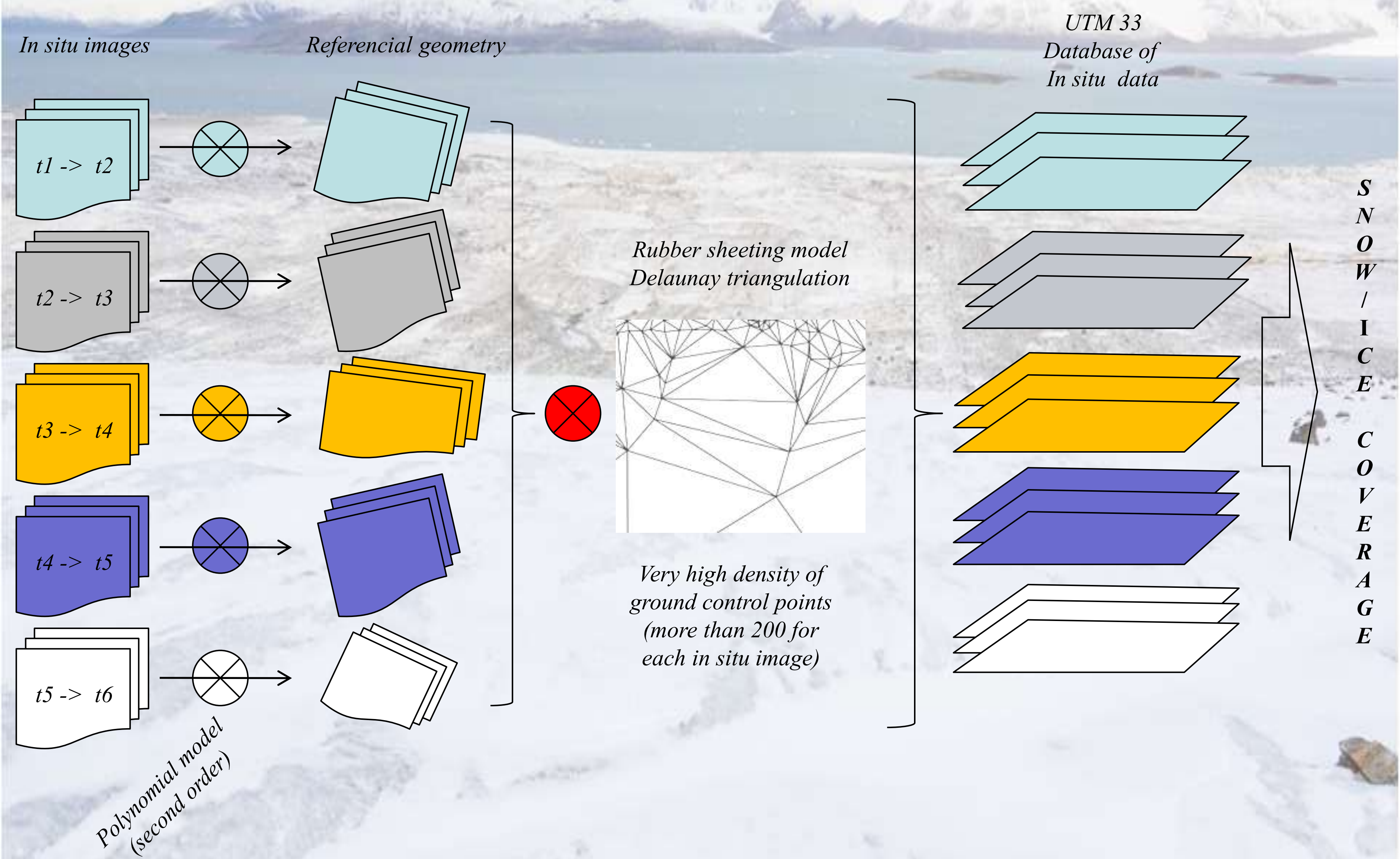
Images for which the geometrical model was not defined must be corrected through a double geometrical transformation to be consistent with the mapping projection.

Source image to be modified

Modified image using a second order polynom, consisitent with the geometry of data acquired in 2009 used as reference for the `` rubber sheeting ’’ method

Images are corrected to match even though the orientation of the camera was changed: a first geometrical transform allows fitting with the parameters of the projection model.

Generalization to all the *in situ* images
(about 1000/camera/year, or a total of 26 000 images since 2007)



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Snow / Ice coverage and quality estimation

Hinkler, J. , Pedersen, S. B. , Rasch, M. and Hansen, B. U.(2002)
'Automatic snow cove r monitoring at high temporal and spatial resolution, using images taken by a standard digital camera',
International Journal of Remote Sensing, 23: 21, 4669 — 4682

Normalized Difference Snow Index - NDSI

$$NDSI = \frac{TM_{band2} - TM_{band5}}{TM_{band2} + TM_{band5}}$$

With digital camera approximation – $NDSI_{RGB}$

$$NDSI_{RGB} = \frac{\overline{RGB} - MIR_{replacement}}{\overline{RGB} + MIR_{replacement}}$$

Where :

$$\overline{RGB} = \frac{R + G + B}{3}$$

$$MIR_{replacement} = \frac{\tau^4 * RGB_{max}}{\overline{RGB}^4}$$

$$\tau^4 = 200(a * \overline{RGB_{high}} + b)$$

a and b empirical parameters depending of camera

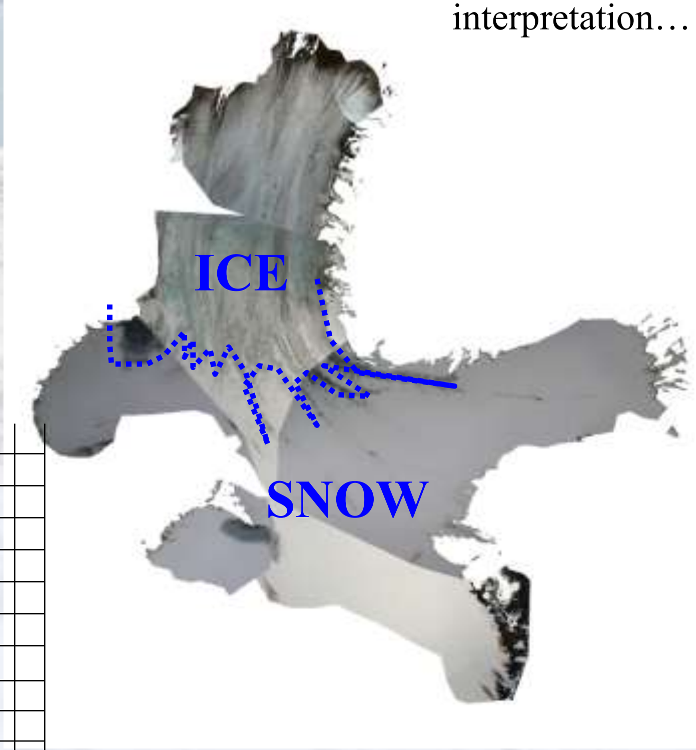
$$\overline{RGB_{high}} = \frac{B^3}{R^3} * G$$

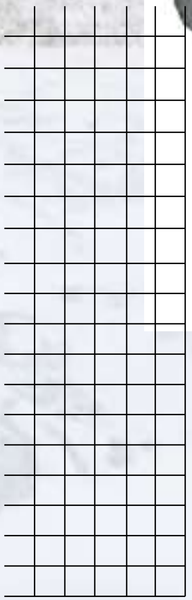
EMPIRICAL

NOT EFFICIENT

WITH SEVERAL CAMERAS

Binary snow and ice visual interpretation…





Snow high/density database

… completed by regular snow drills field measurments (high and snow density)

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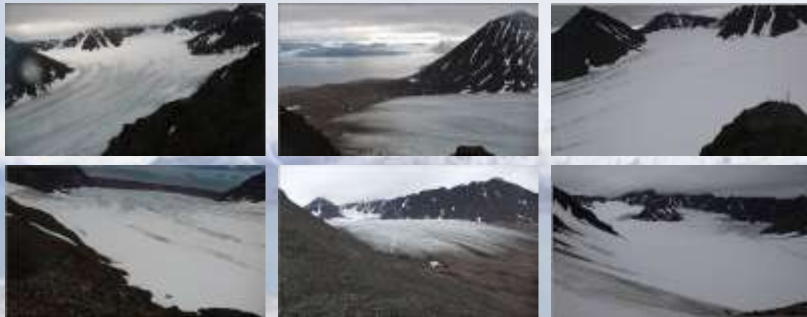
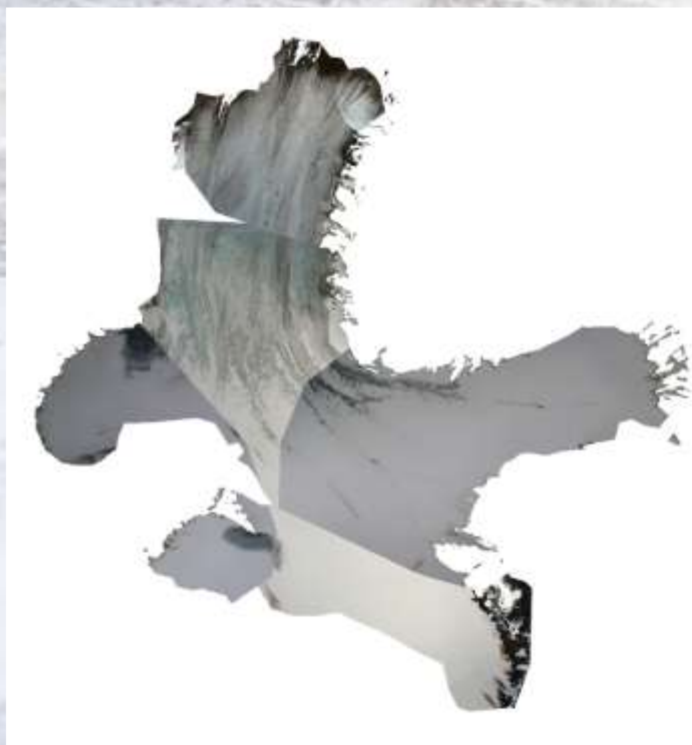


september13th



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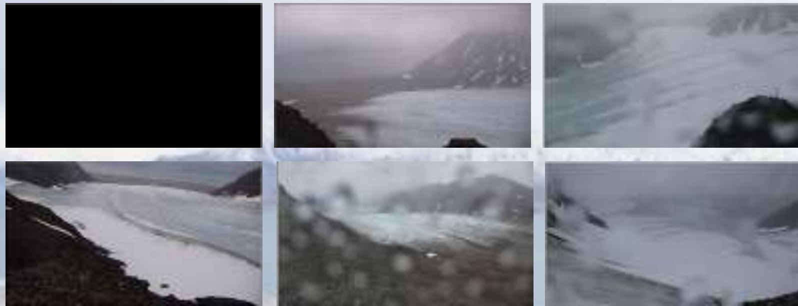

september15th

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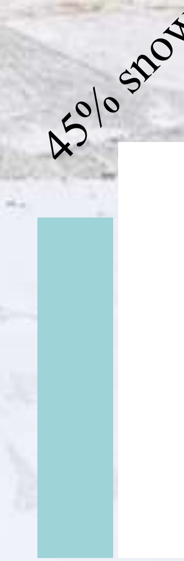
September 20th



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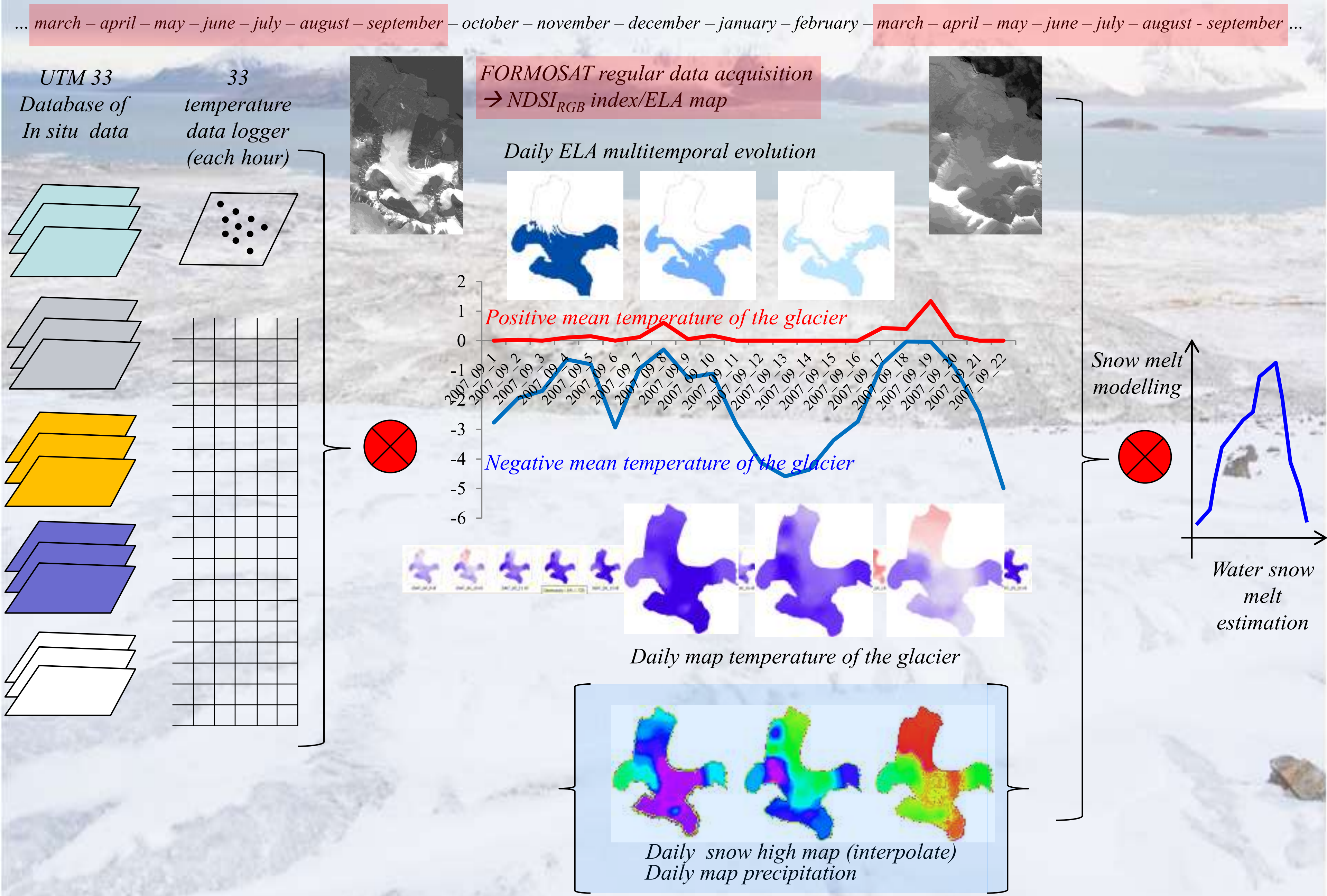
Estimating the fraction of glacier melt in the hydrologic budget



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Simple model of snow melt – day degree fusion model

Day-degree fusion model: $QF_d = (\alpha * d * \beta) * (T_d - T_0) * \frac{stock_d}{stock_{moyen}}$ → Drills field measures since 2008

Can be simplified as: $HF_{ijours} = k * \sum_{i=1}^{n} (T_i - T_0)$

k : coefficent defining the influence of natural and climatic conditions of the basin on melting, 5 mm/degC for snow and 7 mm/degC for ice.

T_i: mean air temperature or maximum daily temperature.
T_0: threshold temperature above which snow melts.

Considering precicipitations, one obtains: $HF_{ijours} = k * (1 + \alpha P_{ijours}) * (T_i - T_0)$

α: fitted parameter, usually 0.0035 mm^{-1}.

P_i : total daily precipitations → Network of Data loggers since 2008

One should additionnaly consider the influence of progressive stock reduction and the accumulation of rain water in snow.

→ Both satellite images and ground pictures give a binary information concerning the presence of snow or presence of ice. This differenciation is very important to determine, for each point on the glacier surface, the melting coefficient *k* of the moment which determines the amount of water coming from the melting of snow and ice.

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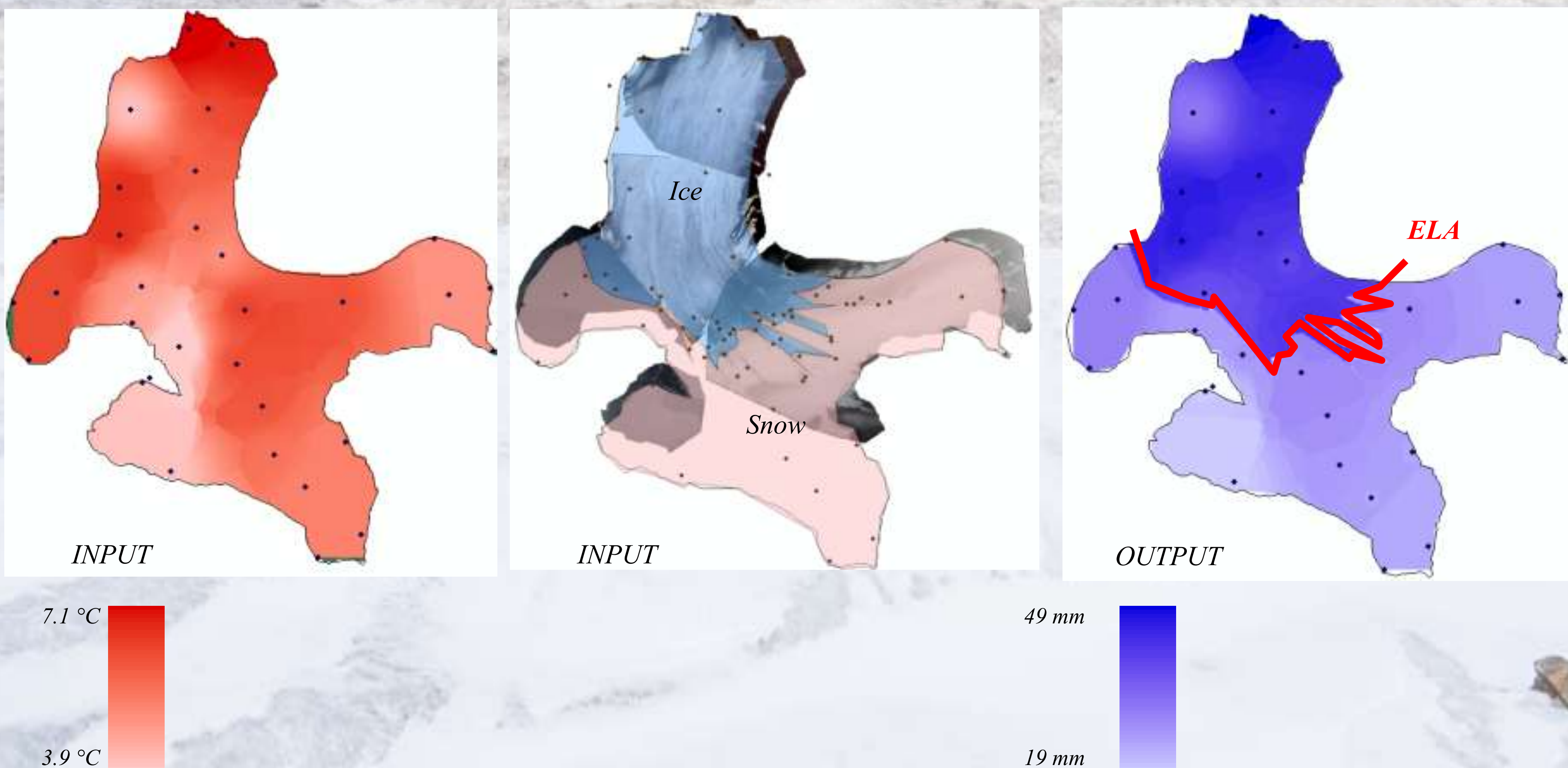
Simple model of snow melt – day degree fusion model
September 15th 2008

Mean daily air temperature IDW interpolate map

Snow/ice coverage from mosaïc of projected in situ *images*

Water height equivalent of snow-ice melt using model
-
map



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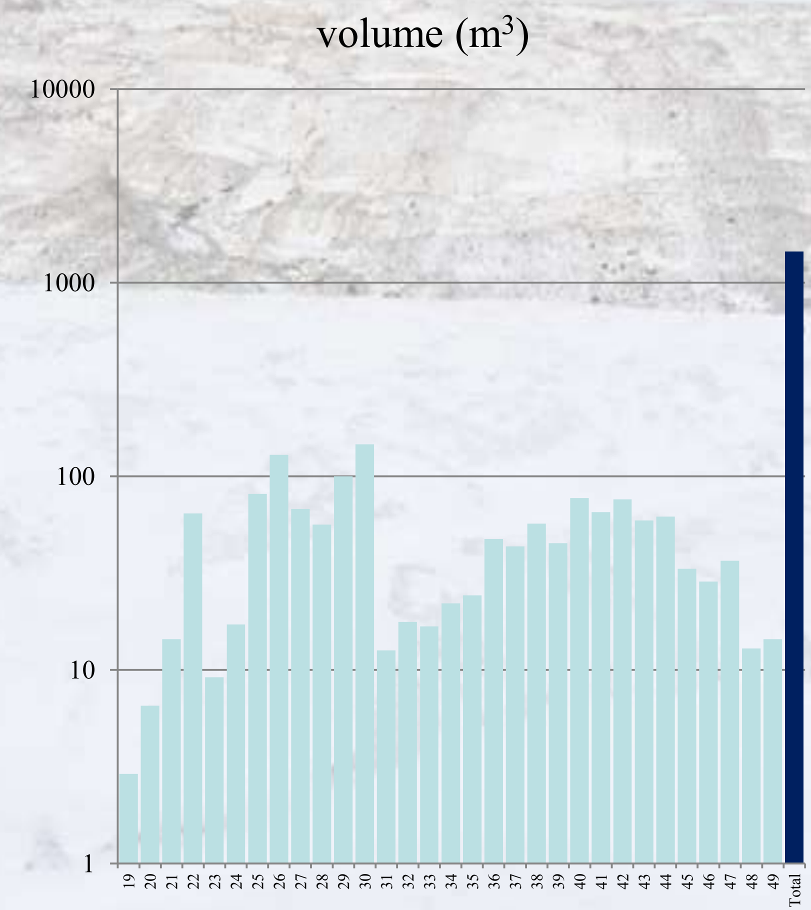
Simple model of snow melt – day degree fusion model September 15th 2008

melt (mm)	nb_pix	area (m²)	volume (m³)
19	3827	15308	290.852
20	8152	32608	652.16
21	17192	68768	1444.128
22	73070	292280	6430.16
23	9954	39816	915.768
24	17897	71588	1718.112
25	81230	324920	8123
26	124249	496996	12921.896
27	62874	251496	6790.392
28	50187	200748	5620.944
29	86301	345204	10010.916
30	122140	488560	14656.8
31	10175	40700	1261.7
32	13808	55232	1767.424
33	12734	50936	1680.888
34	16221	64884	2206.056
35	17345	69380	2428.3
36	32994	131976	4751.136
37	29389	117556	4349.572
38	37509	150036	5701.368
39	28924	115696	4512.144
40	48314	193256	7730.24
41	39769	159076	6522.116
42	45200	180800	7593.6
43	34438	137752	5923.336
44	35221	140884	6198.896
45	18501	74004	3330.18
46	15516	62064	2854.944
47	19447	77788	3656.036
48	6727	26908	1291.584
49	7363	29452	1443.148
Total	1126668	4506672	144777.796

Water height equivalent of snow-ice melt using model

–

Statistic - Diagram



Budget

13.8 mm mean of water equivalent snow melt on the drainage basin.

-

144.7 10^3 m^3 with 56% from snow (81 10^3 m^3 vs 63.7 10^3 m^3 from ice)

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Simple model of snow melt – day degree fusion model
Each day during the flood period

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Conclusion

As a conclusion, we demonstrate in this presentation that the conversion of ground pictures into aerial recomposed images may be successfully made for an Arctic glacierized system, especially during summer period when the hydrological activity is the most intense.

This original approach is very relevant for Arctic where the dynamics of processes is rarely observed and therefore is not easily quantified by classical methods.

We can now estimate snow melt, and hence the water equivalent thickness for each pixel, in order to define the fraction of ice and snow melt in hydrological budgets

Thank you

ISIS
Incitation à l'utilisation Scientifique des Images Spot