An adaptation strategy for airports on warming permafrost in Northern Québec (Nunavik).

By

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UNIVERSITÉ LAVAL

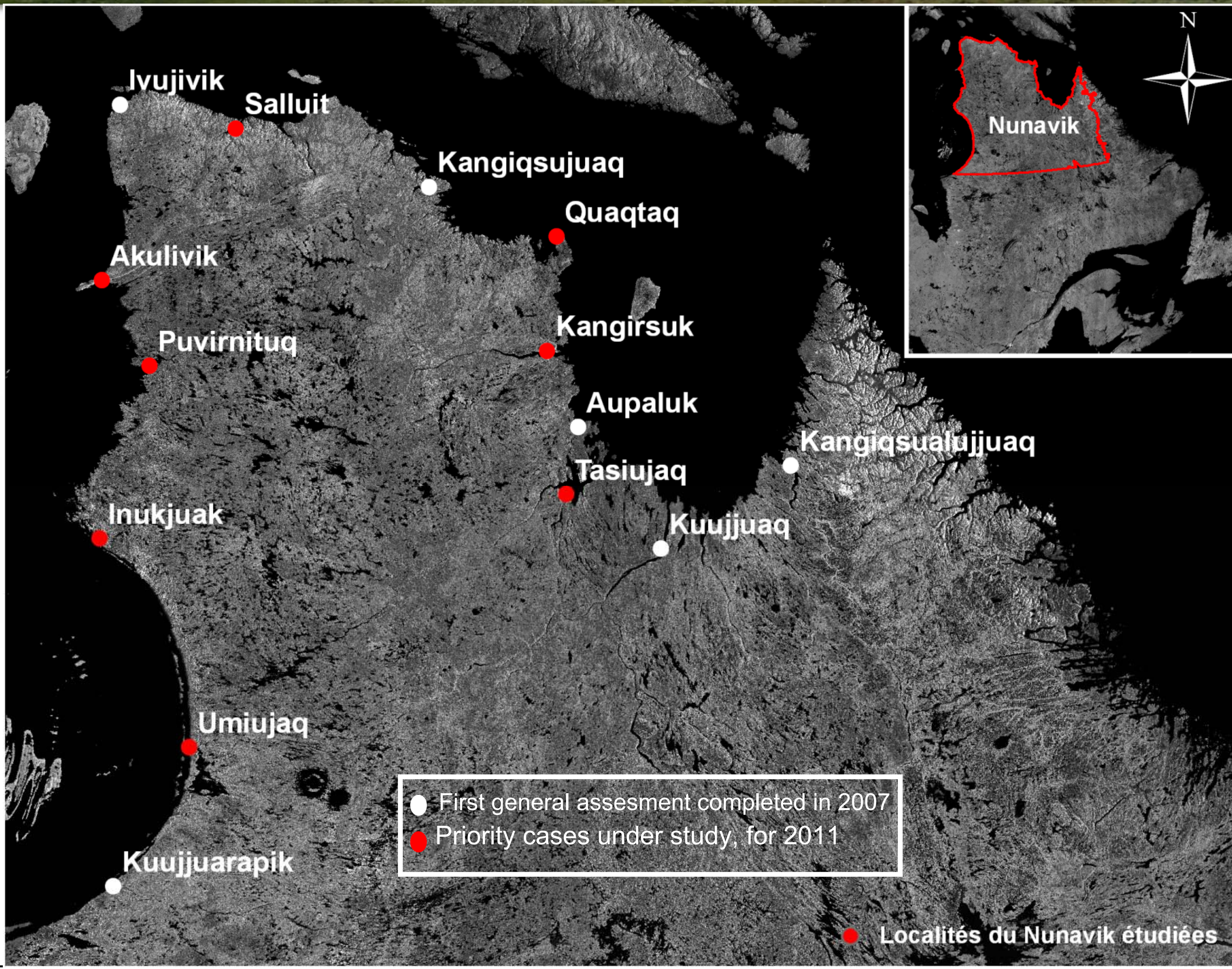
Transports Québec

Centre d'Études Nordiques

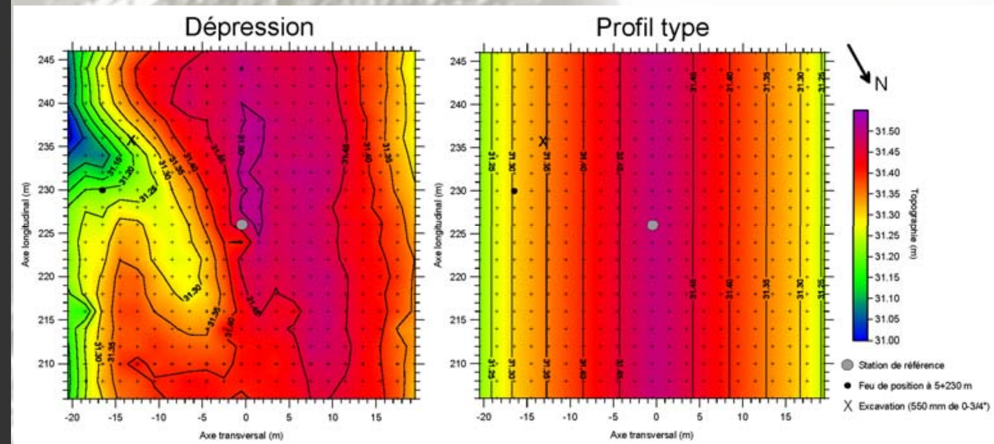
Presentation plan

1. The Nunavik airport adaptation project: goals and timeline.
2. Observed and predicted climate warming
3. Methodology.
4. The Tasiujaq example.
5. The Akulivik example
6. The snow factor
7. Key findings and strategy

The Nunavik Project (MTQ)



Les signes de dégradation du pergélisol sous les pistes



Savard et Fortier (2006)

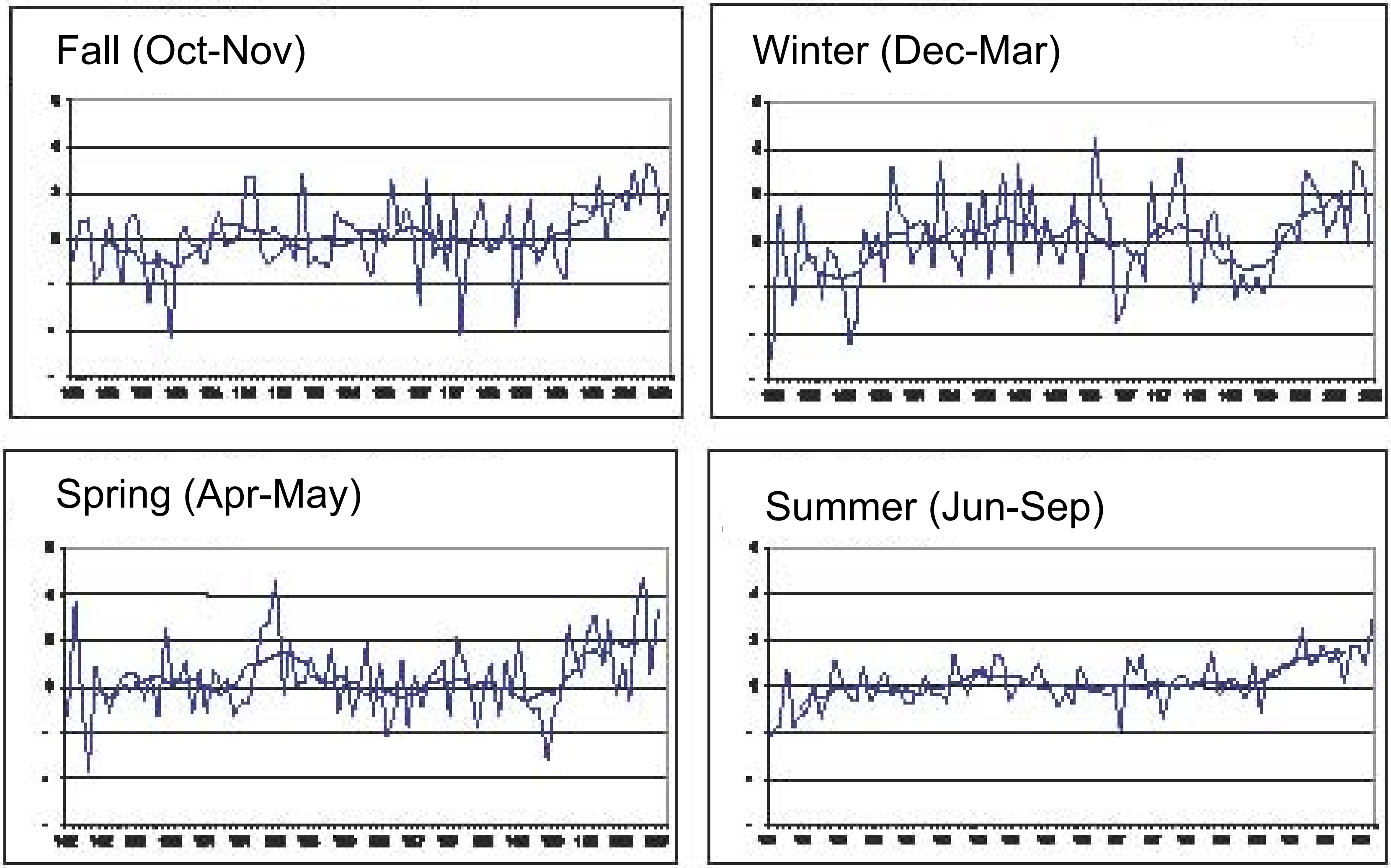


Figure 2. *Regionally-averaged seasonal air temperature anomalies for northern Québec and Labrador (north of 55°N) from the CRU gridded temperature dataset. The smoothed line is the result of passing a 9-term binomial filter.*

Recent climate trends

TABLE 1. Changes in active layer depth between the mid 1990s and 2007 and temperature changes 4 and 7 m deep at selected sites and in different surficial materials in Northern Québec

Site (Cable no)	material	$AL93_{cm}$	$AL07_{cm}$	ΔAL_{cm}	ΔT_{4m}	ΔT_{20m}
Salluit (Sal-154)	Gneiss	279	374	95	1.8	1.0
Salluit (Sal-155)	Till	168	295	182	2.7	1.3
Akulivik (Aku-162)	Till	138	222	84	1.7	-
Akulivik (Aku-232)	Sand/clay	135	143	8	1.6	0.9
Quaqtaq (Quaq-156)	Sand/gravel	151	170	19	1.5	1.5
Quaqtaq (Quaq-158)	Gneiss	416	519[3]	103	1.6	1.2
Puvirnituq (Puv-303)	Gneiss	339	469[2]	130	3.3	1.1
Aupaluk (Aupa-299)	Sand/gravel	155	210	55	1.7	1.0
Tasiujaq (Tas-304)	Sand	113	207	94	1.7	-
Tasiujaq (Tas-roc)	Schist	509	552	43	2.0	1.2
Kangiqsualujjuaq (Kan-231)	Gneiss	607[1]	1100	493	3.4	1.2
Kangiqsualujjuaq (butte côtère)	Argile	252[4]	332[5]	80	1.5	0.05
Umiujaq (Umi-roc)	Basalt	1008[6]	1556[2]	548	1.5	1.2*

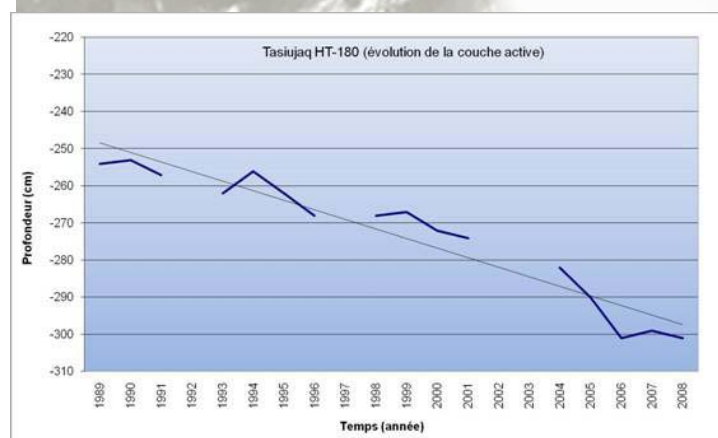
1- 1995 ; 2- 2005, 3- 2004, 4- 1994, 5-2007, 6- 1997, * permafrost now at -0.01 °C

Thickness of active layer

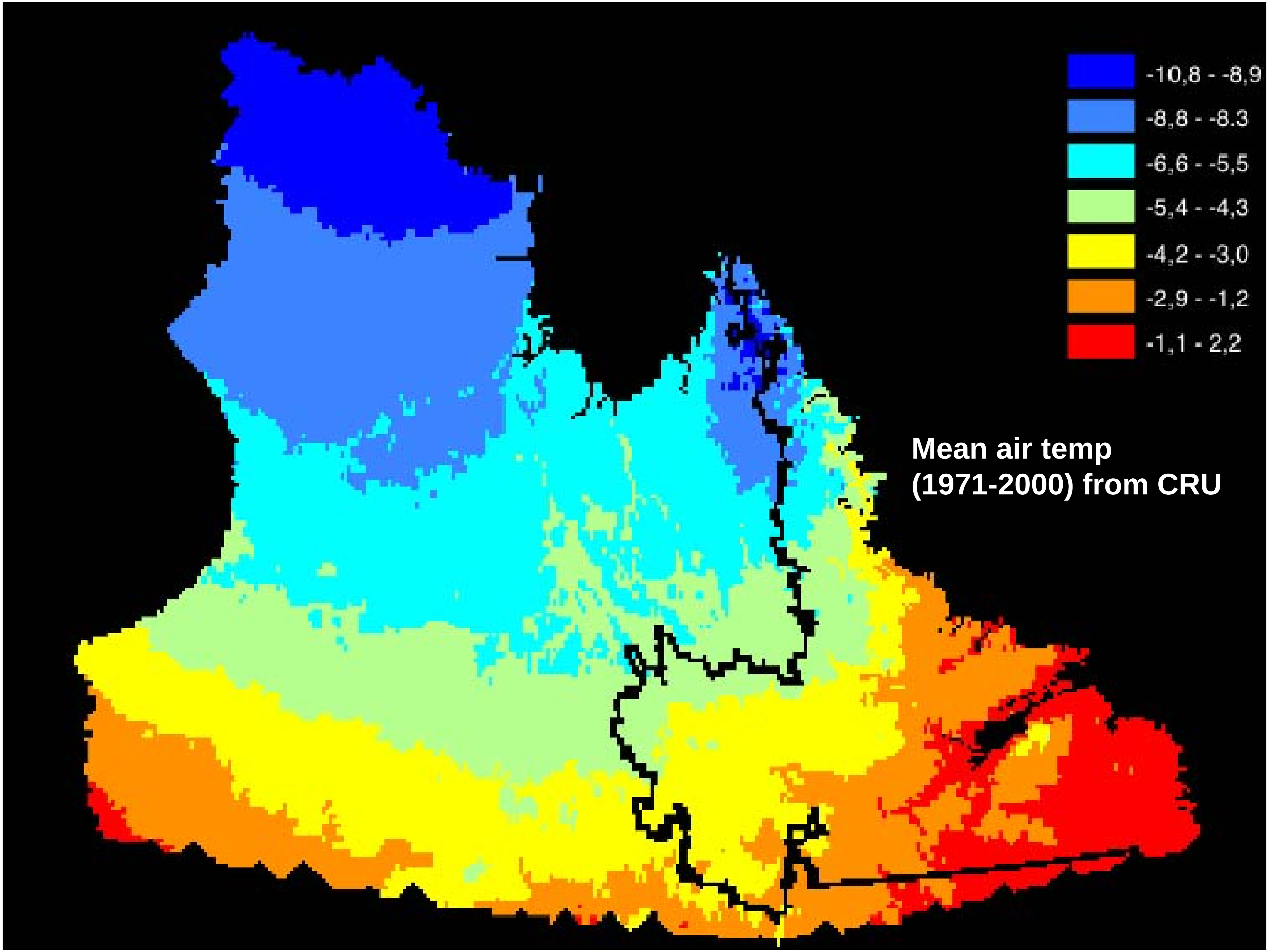
T°C 4 m

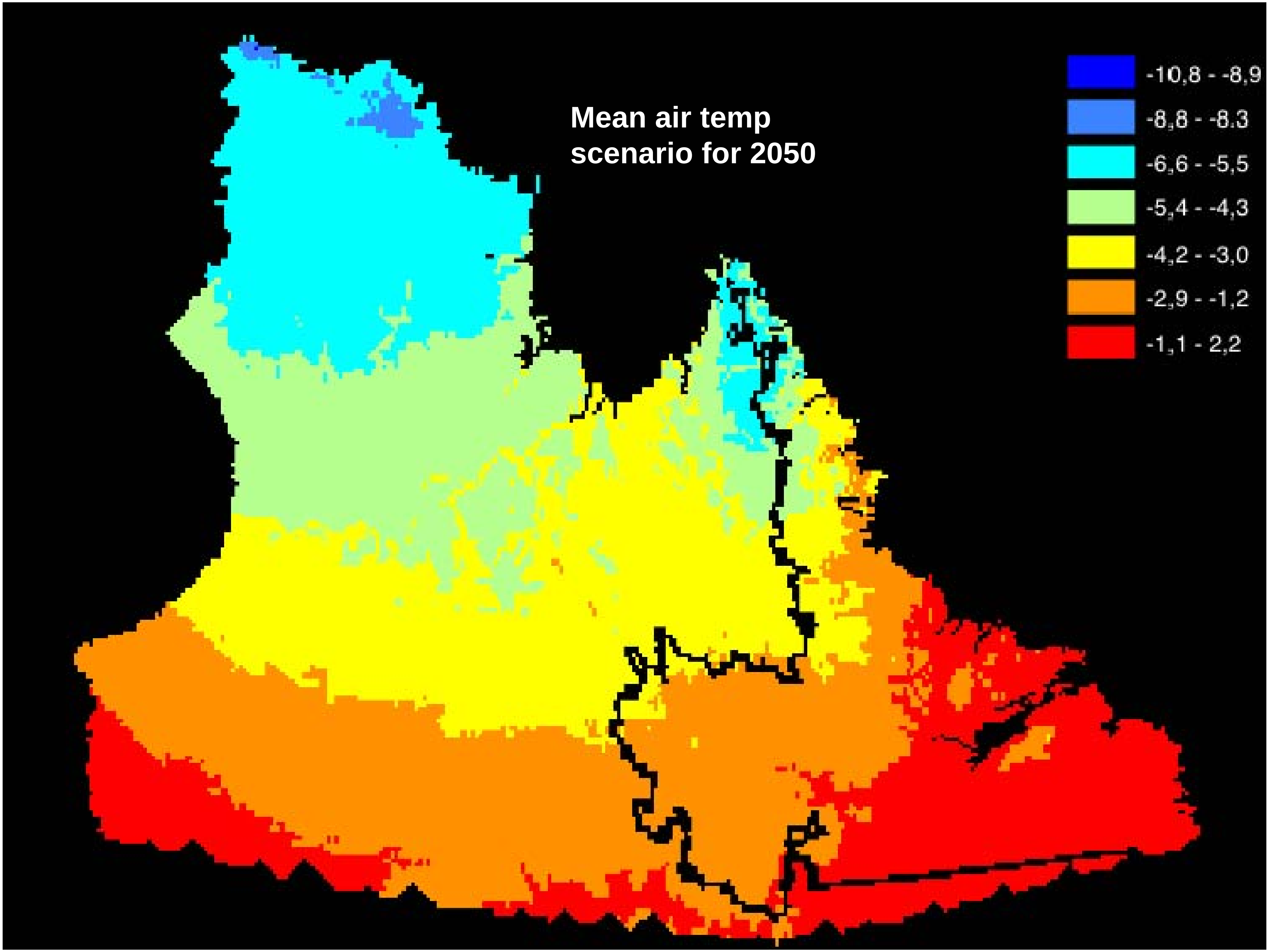
T°C 20 m

Warming over the whole territory.



Smith et al.(2010) Permafrost and Periglacial Processes


-10,8 - -8,9
-8,8 - -8.3
-6,6 - -5,5
-5,4 - -4,3
-4,2 - -3,0
-2,9 - -1,2
-1,1 - 2,2
Mean air temp
(1971-2000) from CRU


Mean air temp
scenario for 2050
-10,8 - -8,9
-8,8 - -8.3
-6,6 - -5,5
-5,4 - -4,3
-4,2 - -3,0
-2,9 - -1,2
-1,1 - 2,2

The Nunavik Project.

Steps

1. Observing actual infrastructure problems.
2. Characterizing permafrost conditions and understanding permafrost- retaled processes affecting runways and roads.
3. Assessing probable impacts of future climate change.
4. Designing solutions with managers and stakeholders.

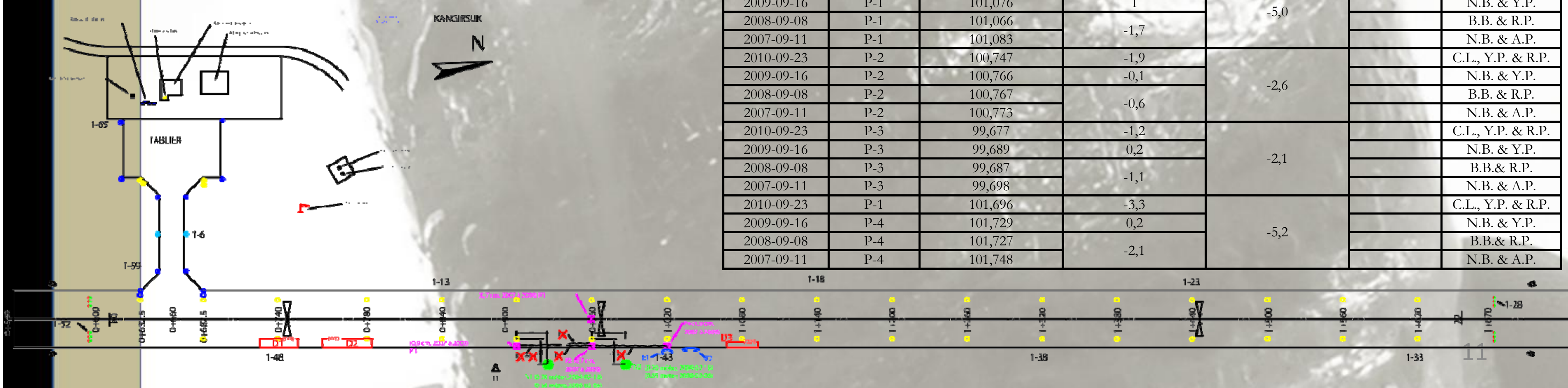
Methodology

- Acquisition and integration of geoscientific data
  - Observations and surveys by MTQ staff
  - High resolution mapping of pre-construction surficial geology
  - Drilling and driling logs
  - Geophysical surveys (GPR, ER) and compilation
  - Permafrost properties (lab analyses and tests)
  - Plans « as built » and history of improvements
  - Thermal analysis, modelling and climate change forecasting
    - Establishing model geometry (domains and mesh)
    - Calibration
    - Validation
    - Simulations
- Data compilation in maps and sections, thermal situation and model outputs
- Assessment of problem diagnostics
- **Interdisciplinary meetings scientists-managers: problem solving, including economical strategy.**

Observation data by MTQ staff

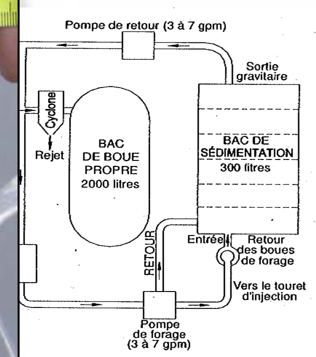
- Characteristics and location of snowbanks accumulation areas and water ponding areas
  - Water puddles (loction length, with, depth)
  - Snow (thicknesses along embankments)
- Characteristics and location of defects
  - Cracks (location, length, width)
  - Depressions (length, width, depth)
- Settlements
  - Annual settlement rates of strategically located plates

Date	Bornes	Élévation (m)	Tassement (cm)	Tassement total (cm)	Remarques	Relevé par :
2010-09-23	P-1	101,033	-4,3	-5,0		C.L., Y.P. & R.P.
2009-09-16	P-1	101,076	1			N.B. & Y.P.
2008-09-08	P-1	101,066	-1,7			B.B. & R.P.
2007-09-11	P-1	101,083				N.B. & A.P.
2010-09-23	P-2	100,747	-1,9	-2,6		C.L., Y.P. & R.P.
2009-09-16	P-2	100,766	-0,1			N.B. & Y.P.
2008-09-08	P-2	100,767	-0,6			B.B. & R.P.
2007-09-11	P-2	100,773				N.B. & A.P.
2010-09-23	P-3	99,677	-1,2	-2,1		C.L., Y.P. & R.P.
2009-09-16	P-3	99,689	0,2			N.B. & Y.P.
2008-09-08	P-3	99,687	-1,1			B.B.& R.P.
2007-09-11	P-3	99,698				N.B. & A.P.
2010-09-23	P-1	101,696	-3,3	-5,2		C.L., Y.P. & R.P.
2009-09-16	P-4	101,729	0,2			N.B. & Y.P.
2008-09-08	P-4	101,727	-2,1			B.B.& R.P.
2007-09-11	P-4	101,748				N.B. & A.P.



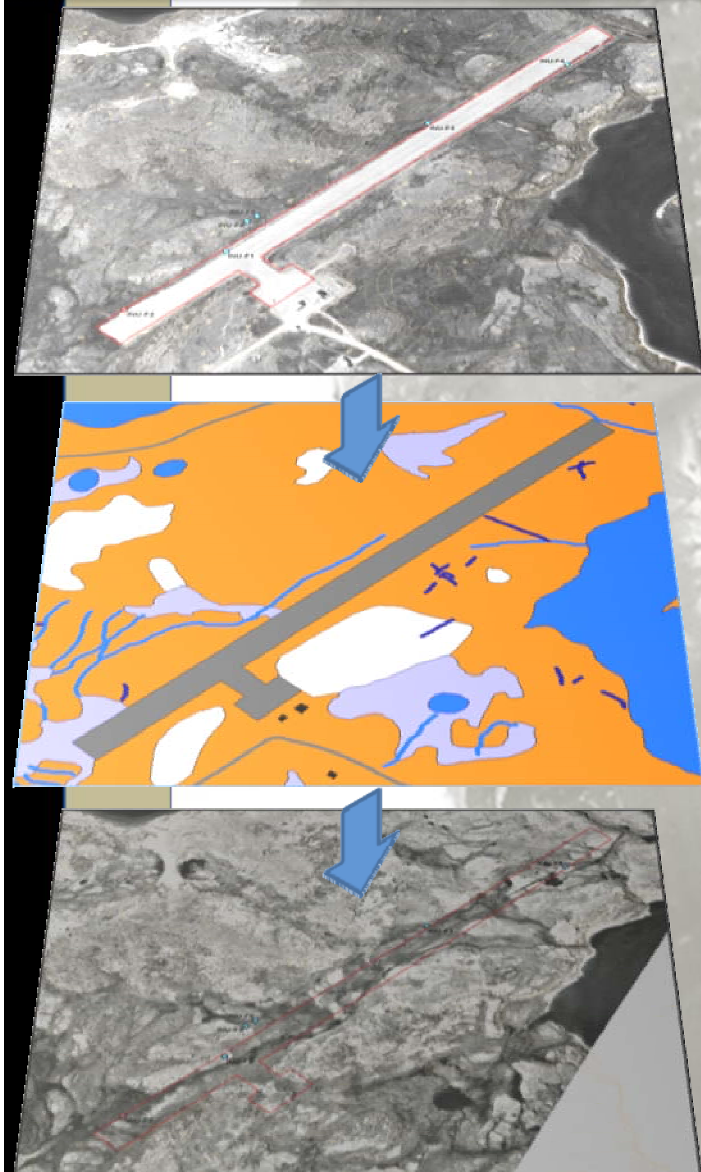
Drilling

- Frozen core recovery at representative locations (surficial geology and problems)

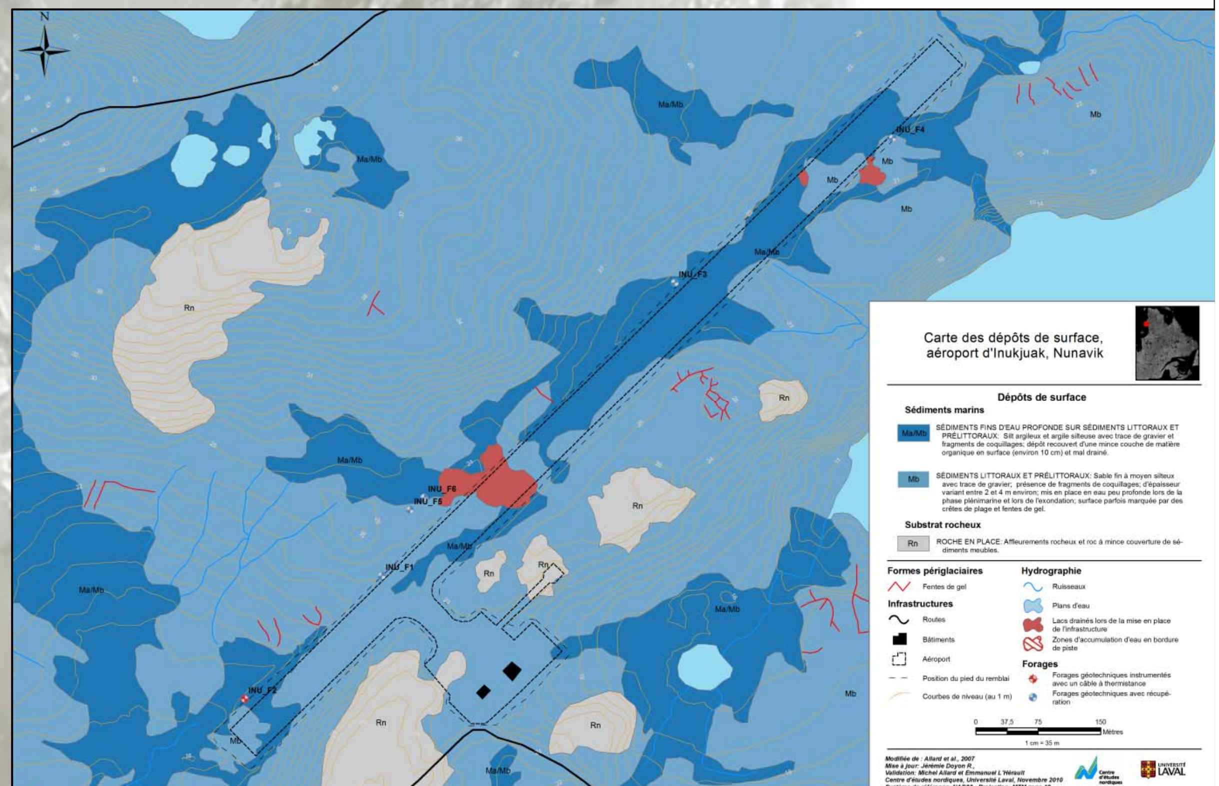


gure 4. Circuit du fluide de forage

Mapping original surficial geology (old air photographs)

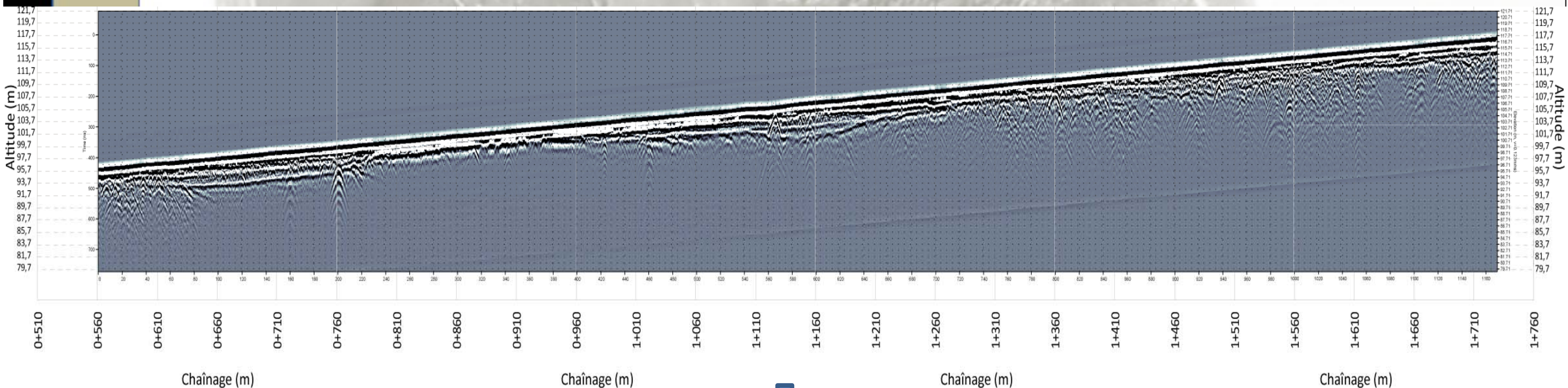


Georeferencing on high precision DEMs



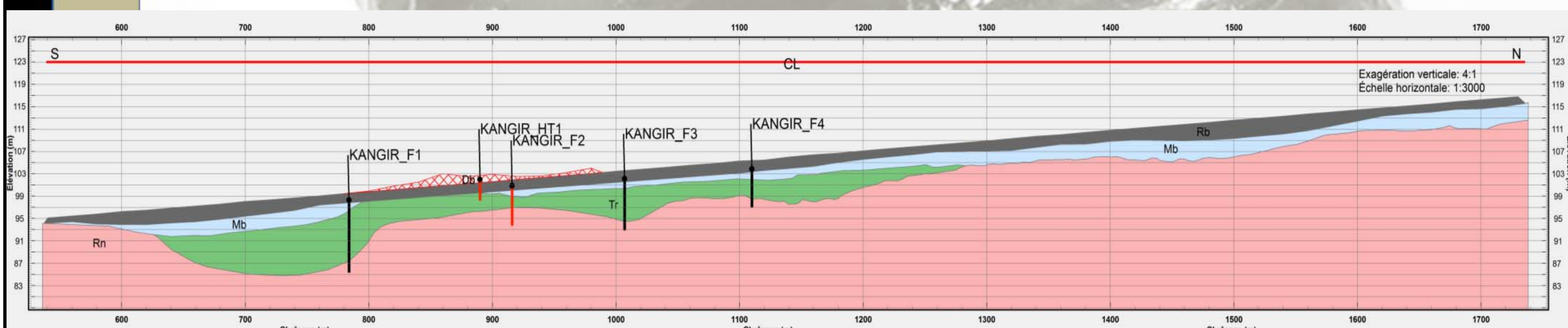
Compilation of drilling and geophysical survey results

– GPR sections



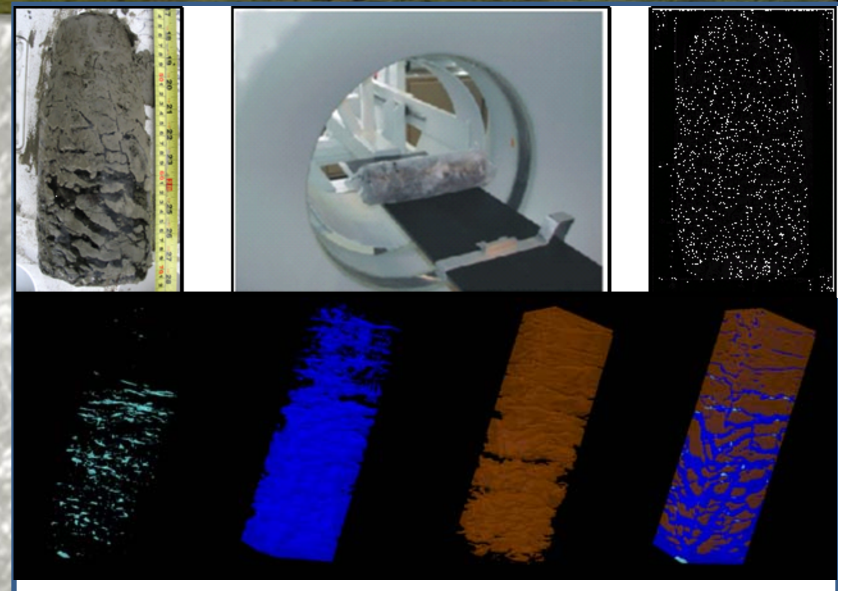
Drill logs

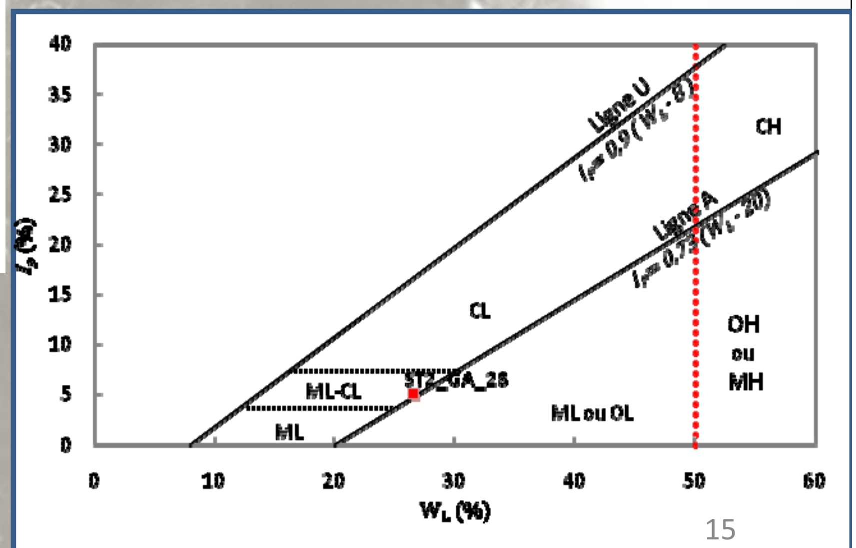
- Validated geological sections



Laboratory analyses

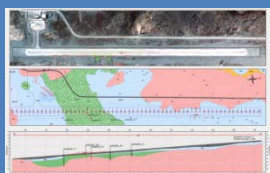
- **Cores**
  - Non frozen
  - frozen
    - Cat-scan
- Water content
- Salt content
- Grain-size
- Atterbergs'limits
- Classification (USCS)
- Consolidation tests
- Creep tests





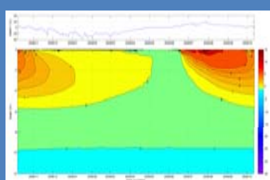
Information integration

Geoscience data



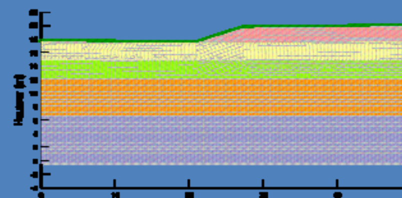
Climate and thermal data

(thermistor cables, 10-20 years)



Heat transfer models

- Meshing
- Simulations



- Calibration
- Validation

Aéroports	Période	Localisation du forage type	Câble de référence	Épaisseur moyenne observée (m)	Épaisseur moyenne simulée (m)	Différence moyenne (%)
Akulivik	2006-2010	HT-183	HT-183	1,81	1,79	-1,1
Quaqtaq	2006-2010	HT-178	HT-156	2,42	2,50	+3,3
Salluit	2004-2007	HT-172	HT-155	2,51	2,53	+0,9
Tasiujaq	2005-2010	HT-181	HT-181	3,43	[illegible]	+2,7
Kangirsuk	2006-2010	[illegible]	[illegible]	2,15	[illegible]	0,4
Inukjuak	2008-2010	[illegible]	[illegible]	5,67	5,67	+0,1
Inukjuak	2008-2010	INU-F3	INU-F2*	2,8*	2,73	+2,2

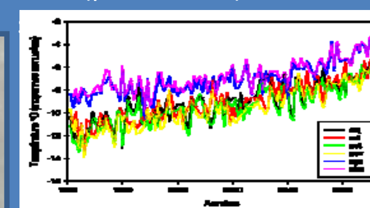
Reconstructed (NARR) and observed climate data (ENV.CANADA, MTQ, CEN)

Climate projections (CRCM

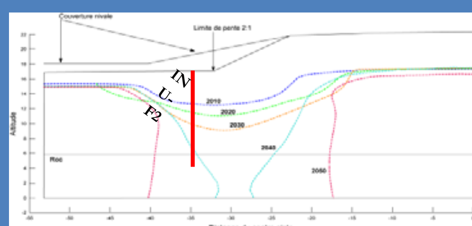
2 runs :

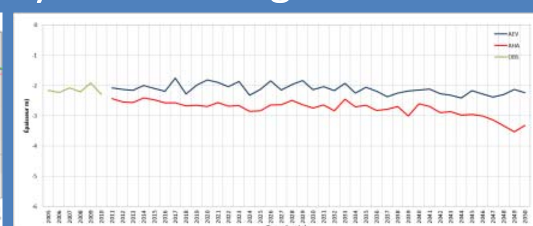
AEV (optimistic scenario)

AHA (pessimistic)



Predicted runway thermal regime





Geotechnical data

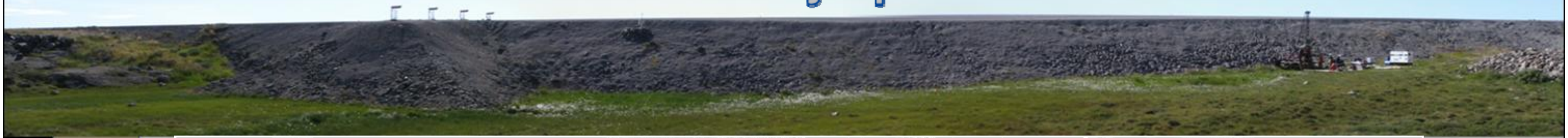
- Water contents
- Cryostructures
- Consolidation
- Creep potential
- Advective heat transfers

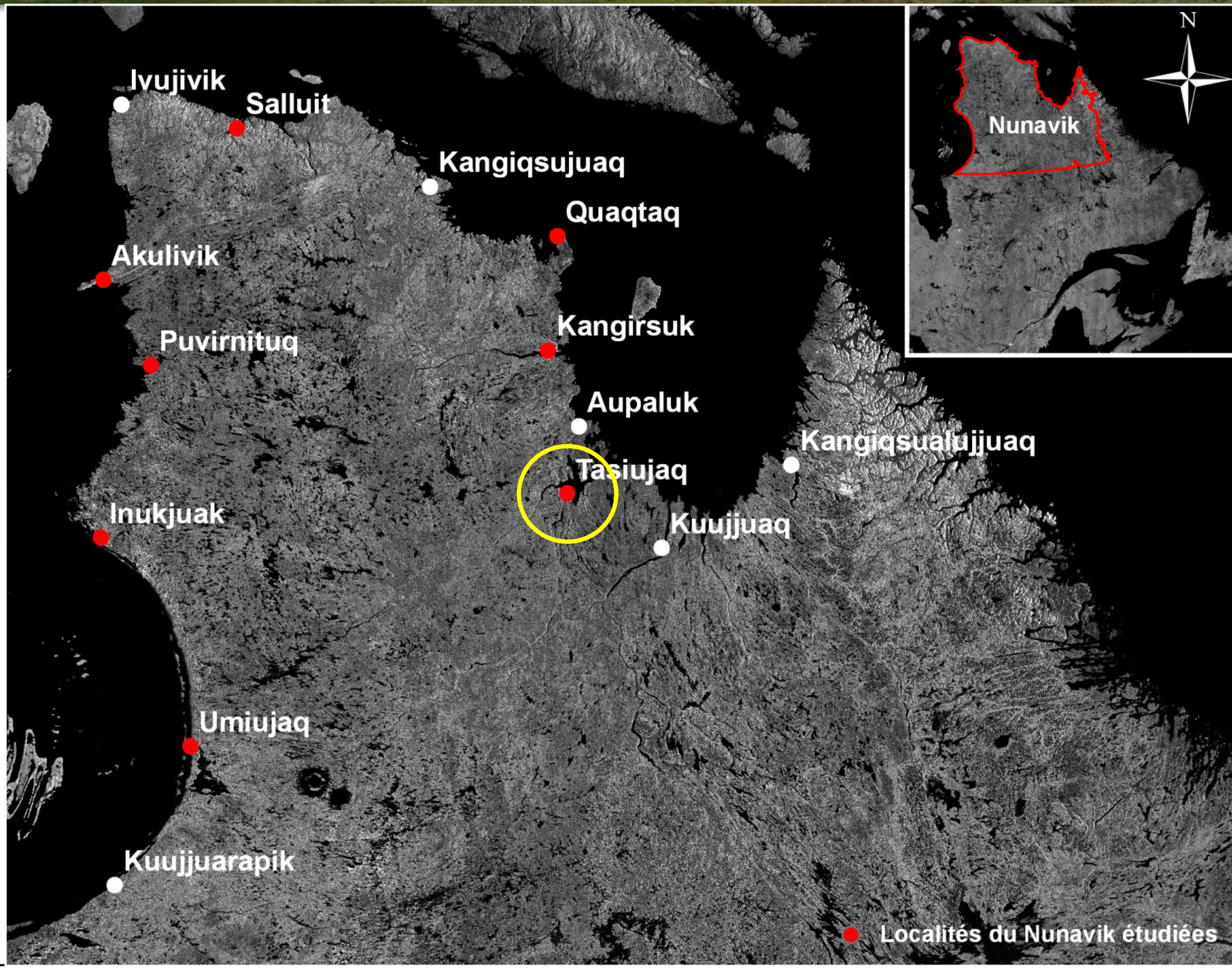
Risk assessment

(delineating sensitive sectors)

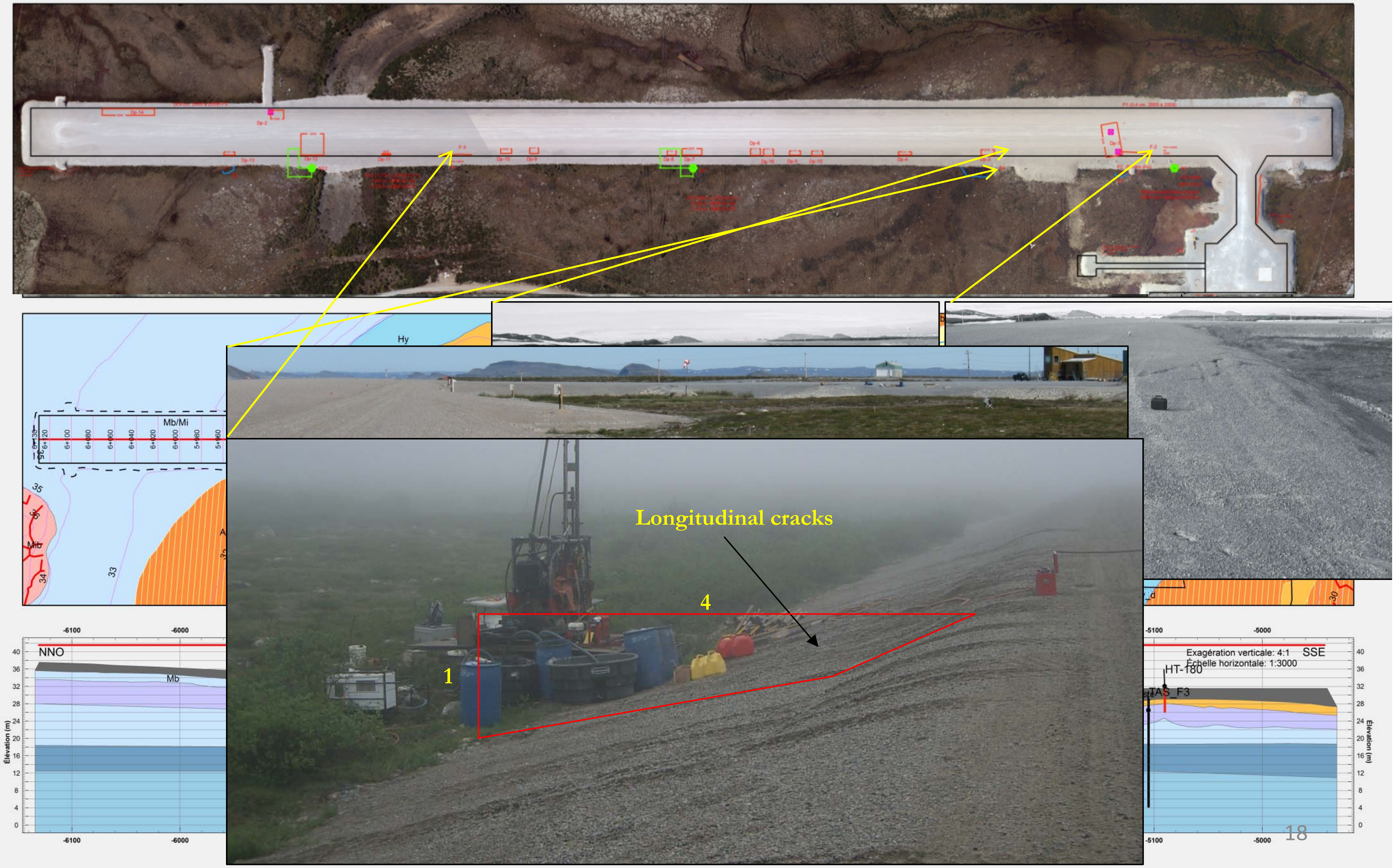
Choice of corrective measures and design of an adaptation strategy

Tasiujaq

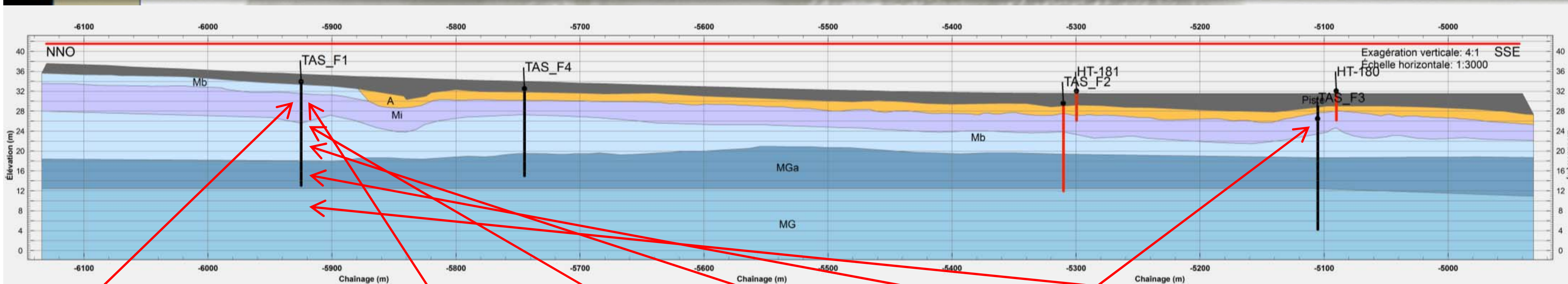



Ivujivik
Salluit
Kangiqsujuaq
Quaqtaq
Akulivik
Kangirsuk
Puvirnituq
Aupaluk
Kangiqsualujjuaq
Tasiujaq
Inukjuak
Kuujjuaq
Umiujaq
Kuujjuarapik
Localités du Nunavik étudiées
N
Nunavik

Tasiujaq
Geoscience data



Tasiujaq
geotechnical parameters

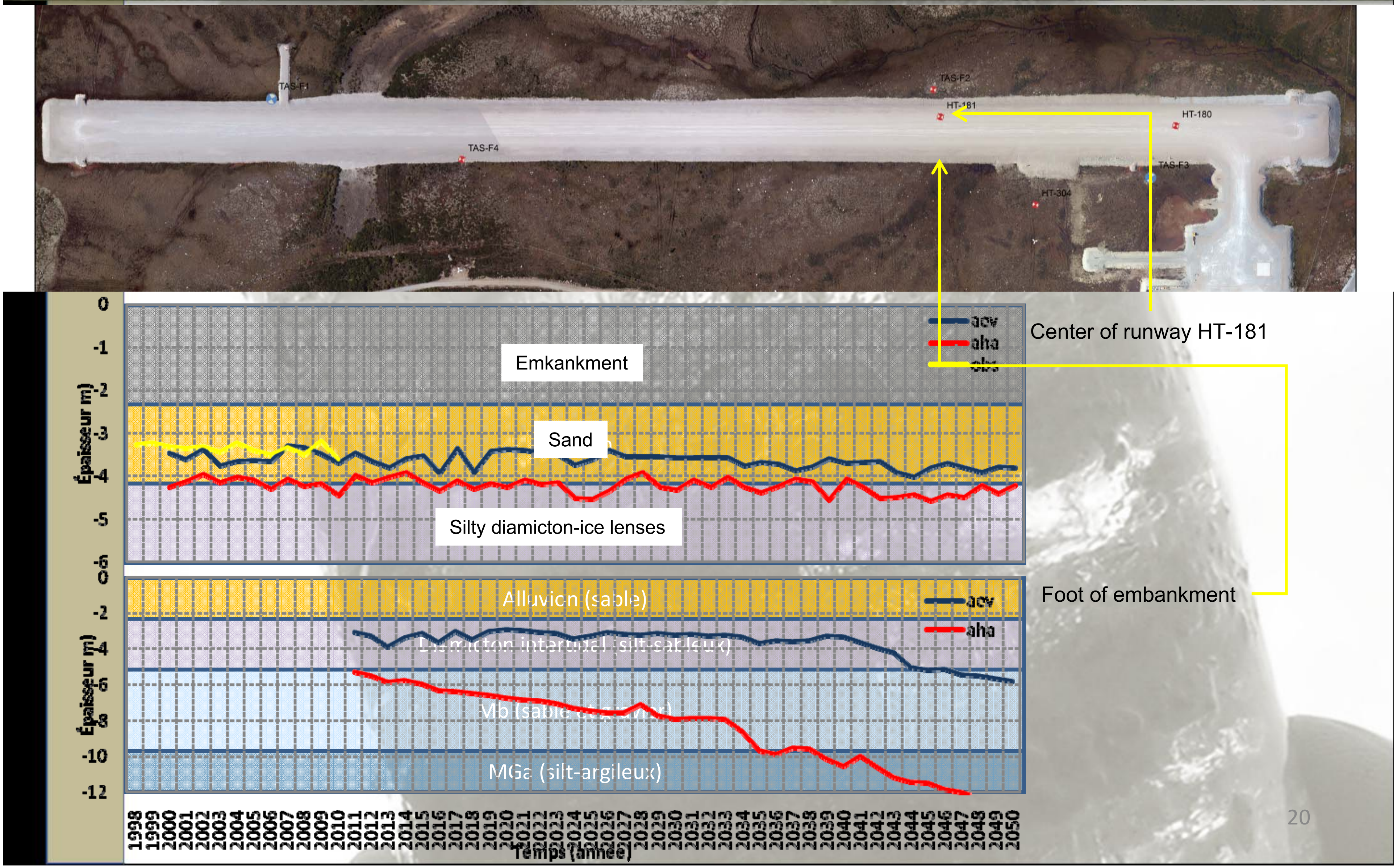


TAS_F1_3		
Type d'essai	Ess[illegible]	[illegible]u dégel
Contrainte (kPa)	100	200
Hauteur (mm)	102,[illegible]	100,2
Diamètre (mm)	65,0	65,0
Volume (cm³)	338,[illegible]	332,5
Indice des vides (e_f)	0,51[illegible]	0,483
Taux de consolidation	10,7[illegible]	12,4%
Teneur en eau		

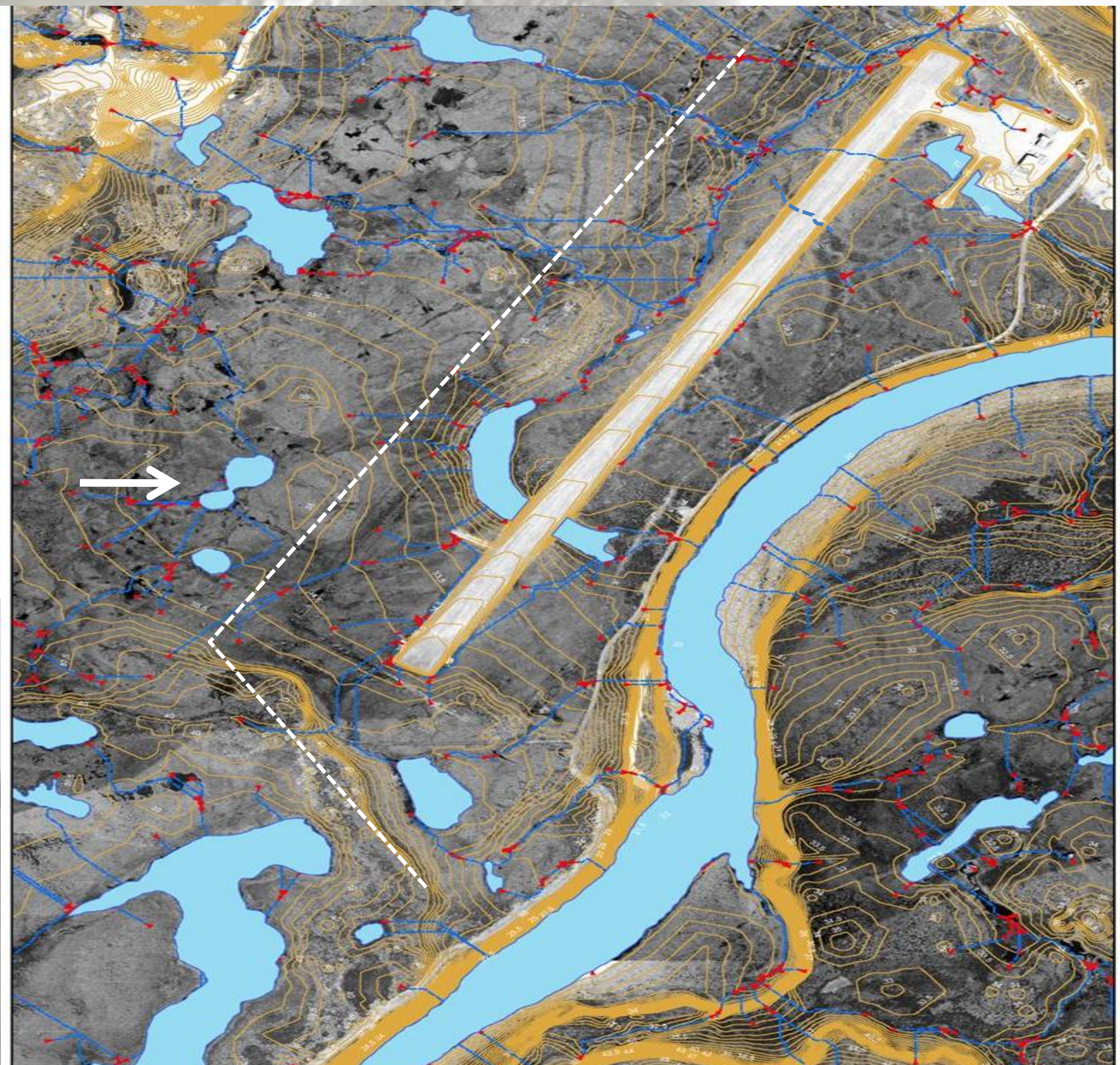
TAS_F3_321_333			
Type d'essai	Essai de consolidation au dégel		
Contrainte (kPa)	100	150	200
Hauteur (mm)	93,0	91,7	90,4
Diamètre (mm)	65,0	65,0	65,0
Volume (cm³)	308,6	304,3	300,0
Indice des vides (e_f)	0,603	0,581	0,558
Taux de consolidation	11,9%	13,2%	14,4%
Teneur en eau	25,5%		

Tasiujaq

Model predictions of permafrost conditions



Tasiujaq
Drainage plan



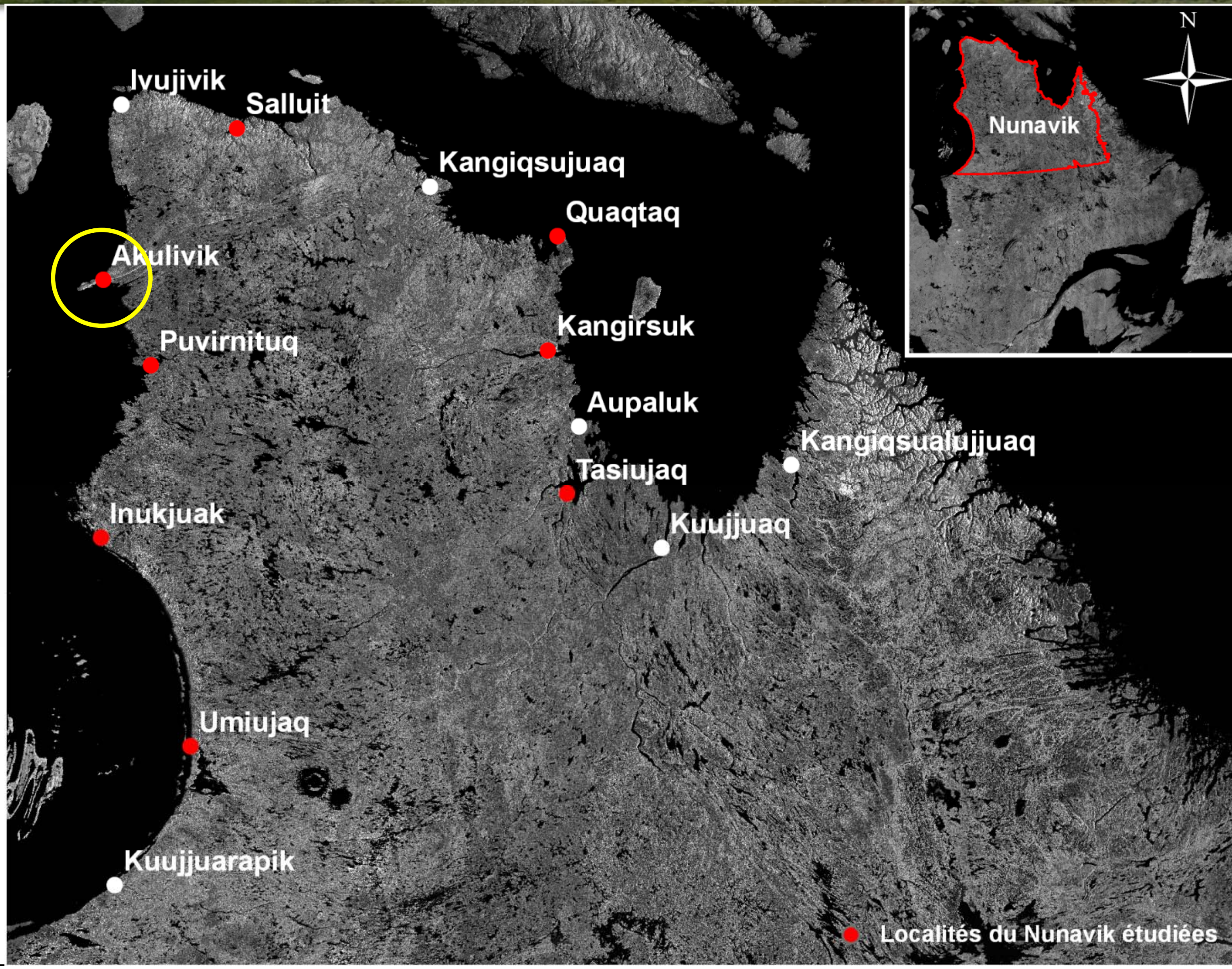
Tasiujaq
Expected settlement

1. Center of runway:
   - Increase of active layer depth by 10 cm from 2005 to 2009
     - Measured settlement of 0.4 cm from 2005 to 2009 (P-1)
     - Corresponds with a consolidation ratio of ≈ 4% (Alluvium =>sand)
   - Current active layer depth (2010): 3.63 m (HT-181)
   - Predicted increased of thaw depth to 2050 (AEV et AHA): ≈ 0.50 – 0.60 m
   - Thaw will penetrate into the ice-lens rich diamicton (intertidal sediments) under the pessimistic scenario (AHA)
     - Given a measured consolidation ratio between 10 and 15 %, 5 to 10 cm settlements are likely to occur.
2. Runway sides:
   - Current active layer depth : ??? But estimated to be 6-7 m from data at similar sites.
   - 8.8 cm settlement from 2005 to 2009 (P-3)
   - Given the 10-15 % consolidation ratio, this corresponds to between 0.88 et 1.32 m of active layer deepening (permafrost thaw).
   - More consolidation tests being done
   - Salinity to be included in the next model runs.

Tasiujaq
Adaptation strategy

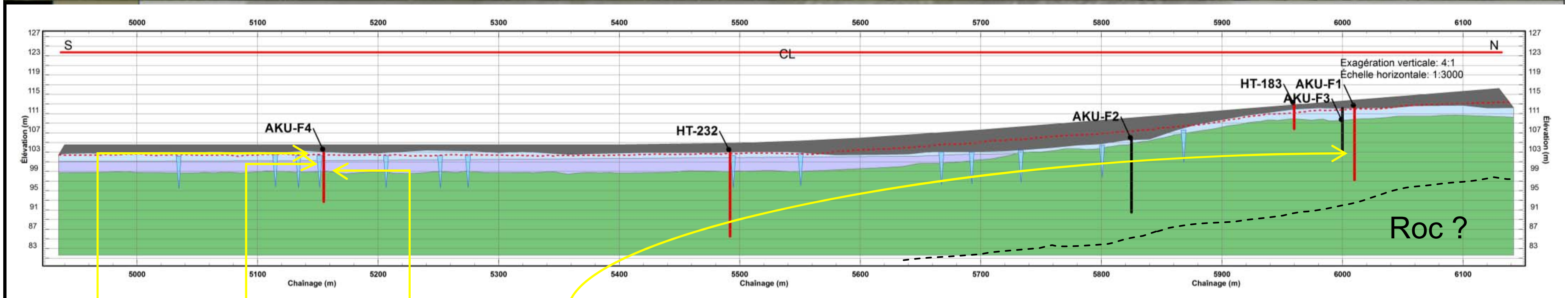
Short term (1-2 years)	Medium term (2-5 years)	Long term
Keep recharging Extract/produce required gravel. Pit available Make a wind-snow study and asses possible installation of a snow fence	Reduce snow accumulations along embankments (snow fence; removal strategy) Modify terrain drainage to prevent ponding along the runway and water seepage underneath (exploit the pre-construction microtopography)	Reduce embankment slopes Continue monitoring of deformations and temperatures.

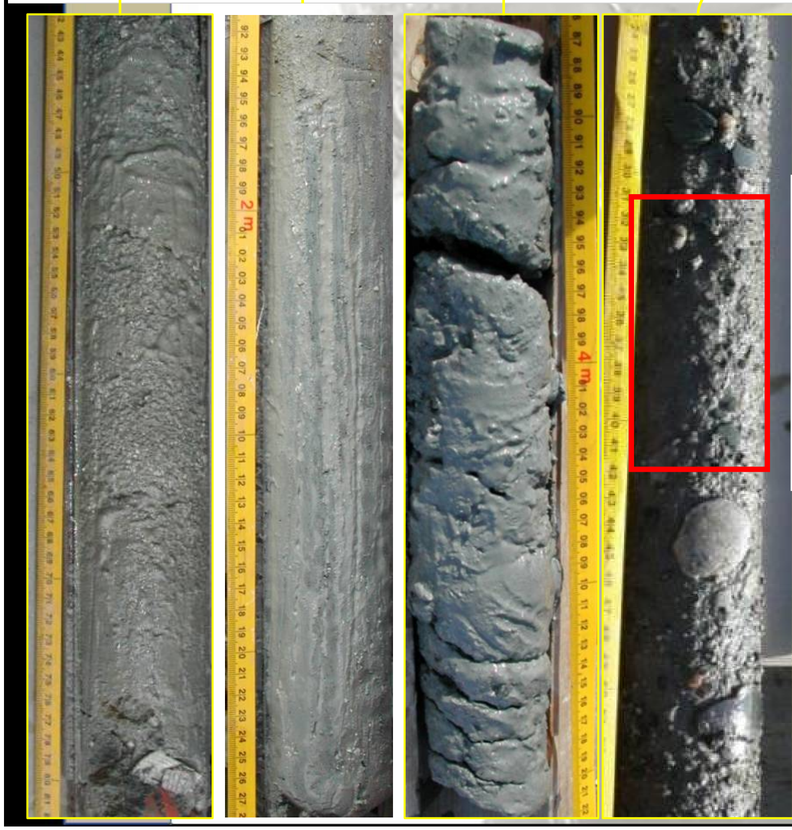
d'Akulivik

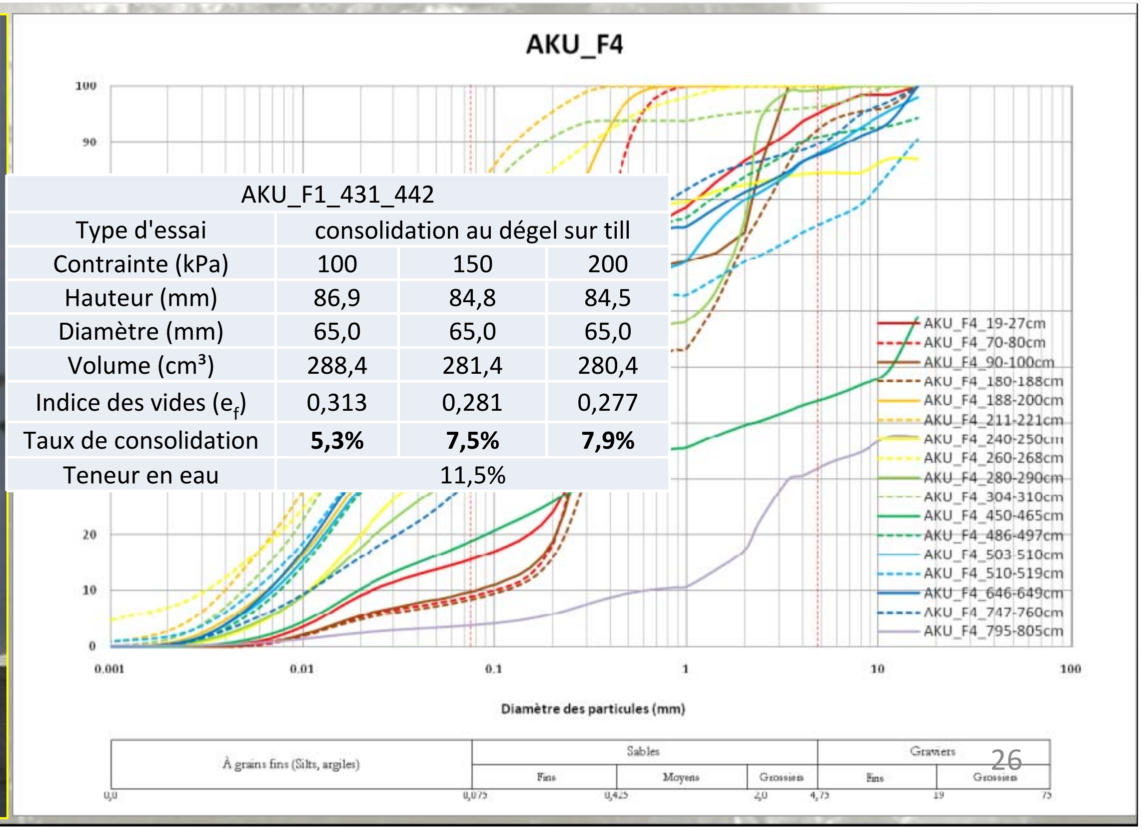

Ivujivik
Salluit
Kangiqsujuaq
Quaqtaq
Akulivik
Puvirnituq
Kangirsuk
Aupaluk
Kangiqsualujjuaq
Tasiujaq
Kuujjuaq
Inukjuak
Umiujaq
Kuujjuarapik
N
Nunavik
Localités du Nunavik étudiées

TABLIER
5+000
5+060
5+100
5+130
5+160
5+220
5+280
5+340
5+400
5+460
5+520
5+580
5+640
5+700
5+760
5+820
5+880
5+940
6+000
6+070
R
Mb/R
Tr
Hy
Hy_d
AKU_F3
Mb/Tr
N
Élévation (m)
Chaînage (m)
5000
5100
5200
5300
5400
5500
5600
5700
5800
5900
6000
6100
127
123
119
115
111
107
103
99
95
91
87
83

Akulivik Geotechnics

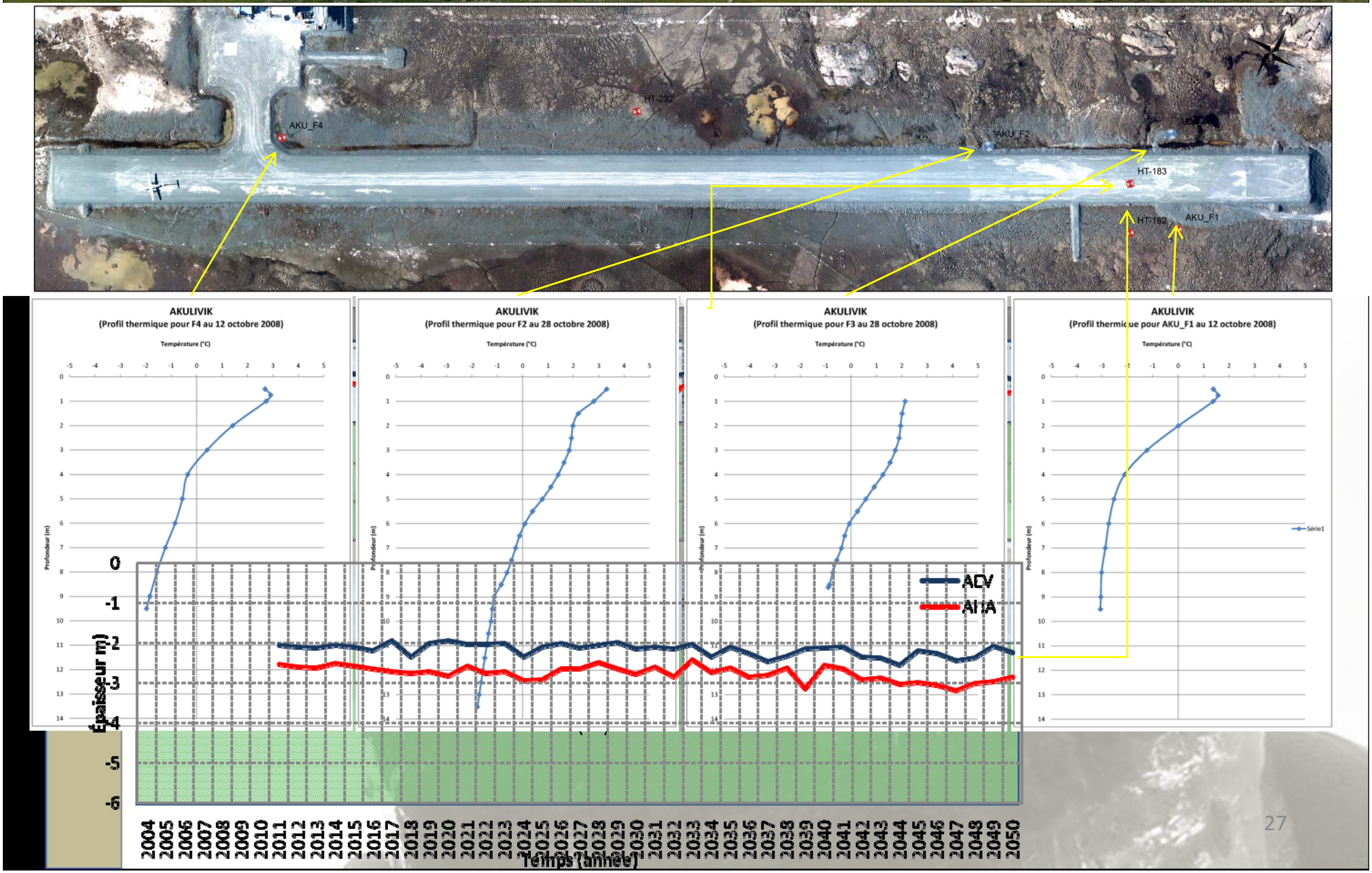




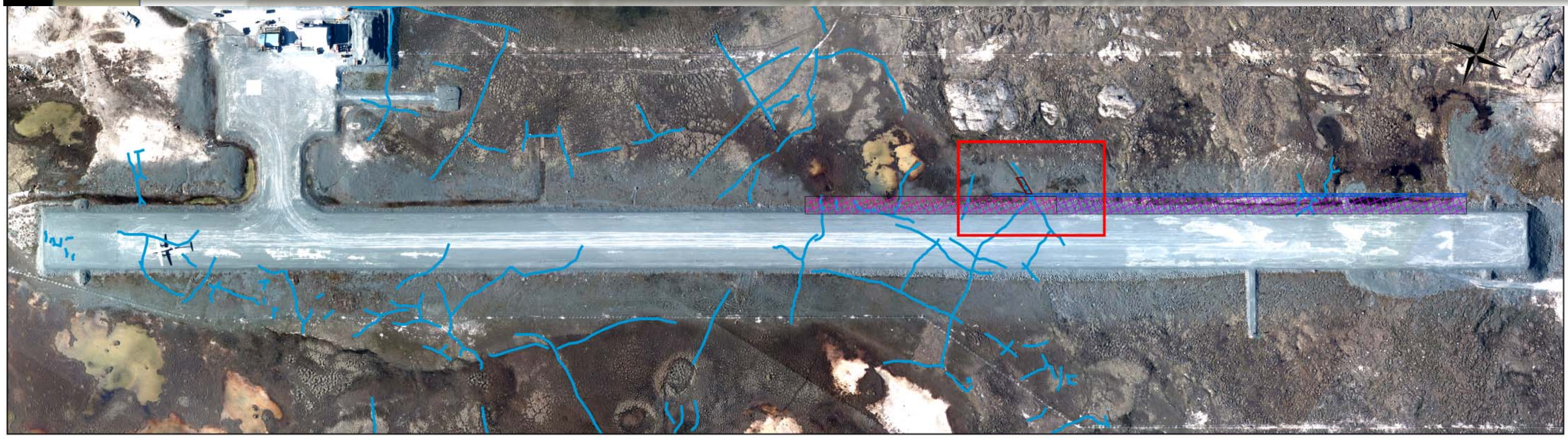


AKU_F1_431_442			
Type d'essai	consolidation au dégel sur till		
Contrainte (kPa)	100	150	200
Hauteur (mm)	86,9	84,8	84,5
Diamètre (mm)	65,0	65,0	65,0
Volume (cm³)	288,4	281,4	280,4
Indice des vides (e_f)	0,313	0,281	0,277
Taux de consolidation	**5,3%**	**7,5%**	**7,9%**
Teneur en eau	11,5%		

Akulivik
Thermal modelling



Akulivik
Adaptation Plan



Sillons de polygones à coins de glace

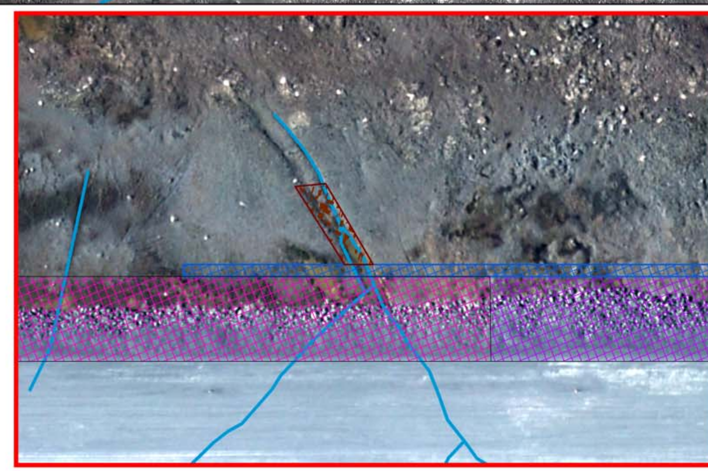
Remblai avec pente adoucie (1:4) (remblai)

Remblai avec pente adoucie (1:4) (déblai/remblai)

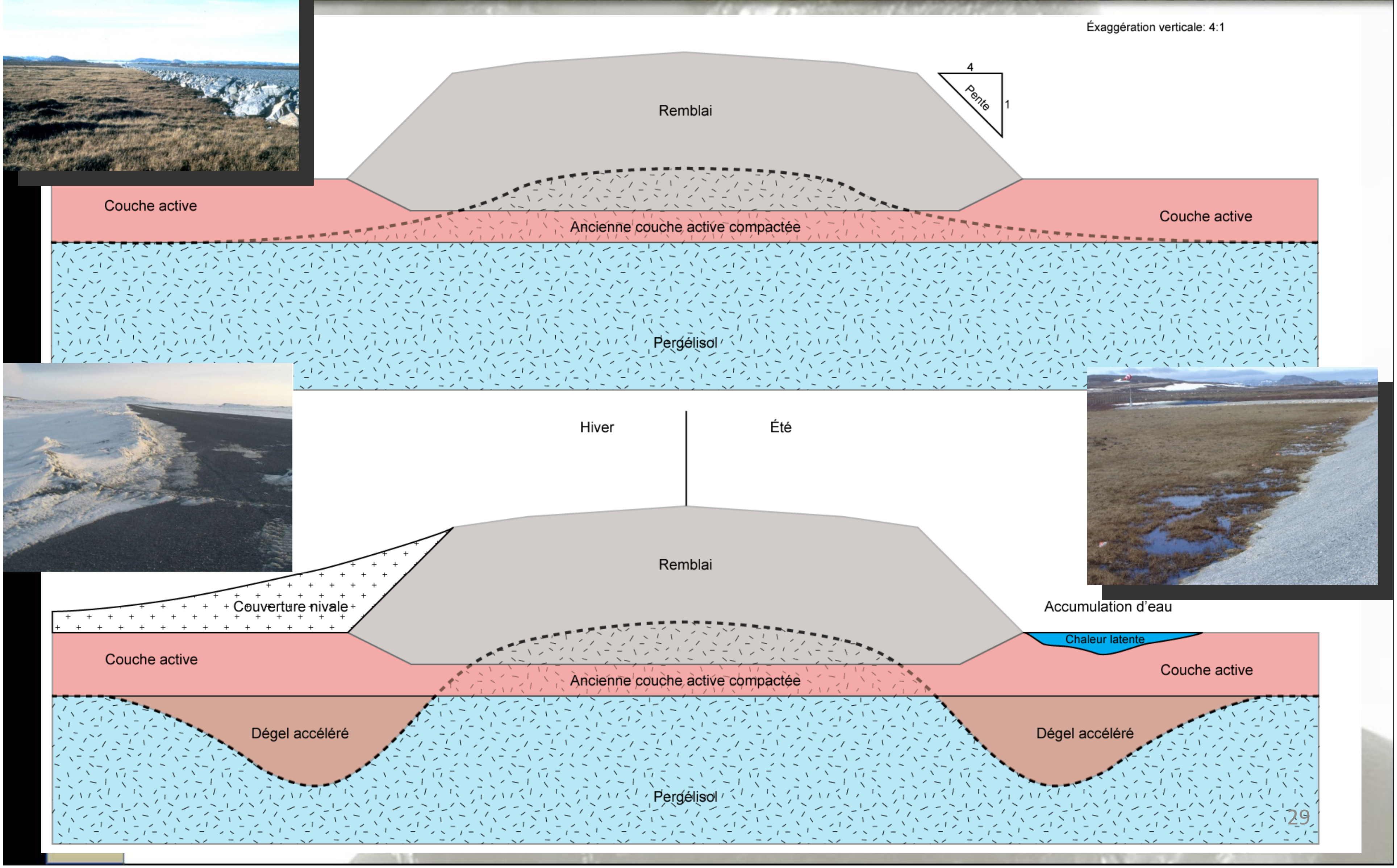
Emplacement du nouveau fossé de décharge

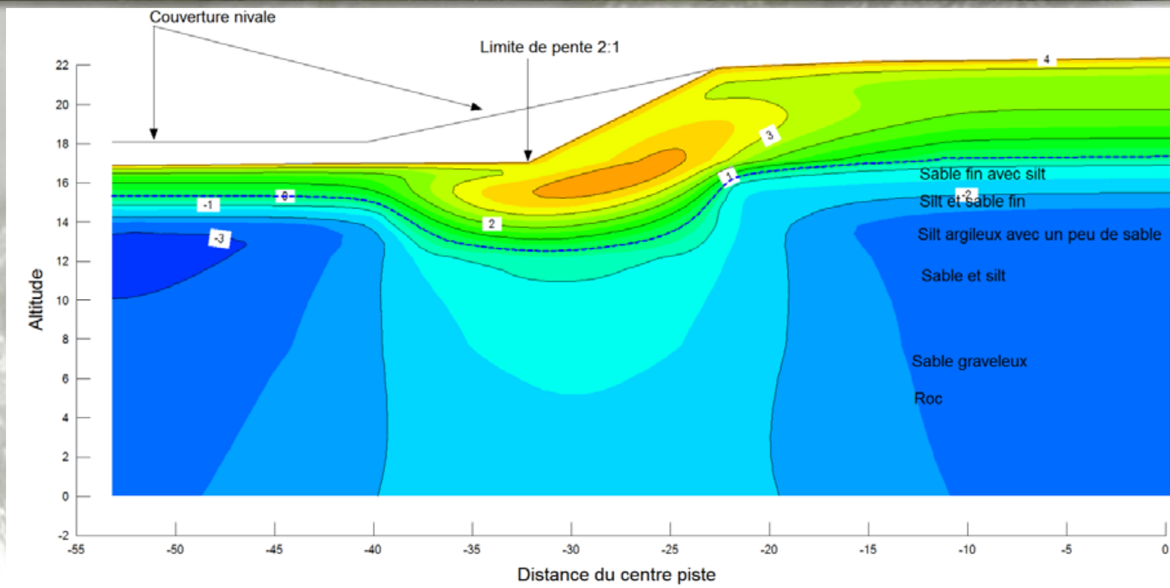
Section des sillons de polygones à coins de glace à combler avec de la tourbe

0 25 50 100
Mètres

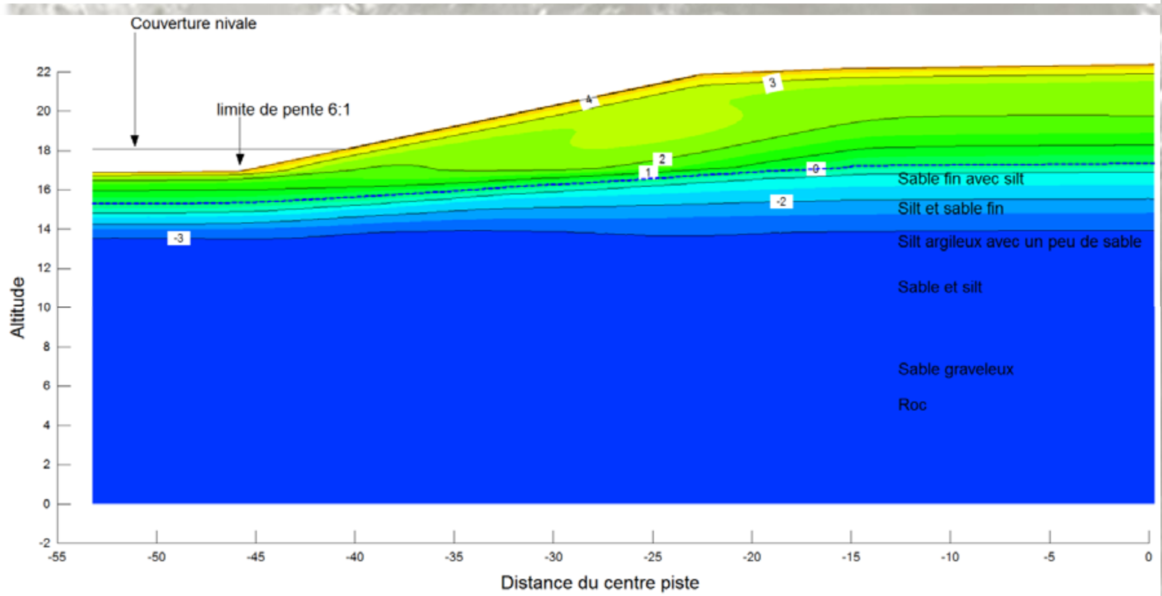


The snow factor





Couverture nivale
Limite de pente 2:1
Sable fin avec silt
Silt et sable fin
Silt argileux avec un peu de sable
Sable et silt
Sable graveleux
Roc
Altitude
Distance du centre piste



Couverture nivale
limite de pente 6:1
Sable fin avec silt
Silt et sable fin
Silt argileux avec un peu de sable
Sable et silt
Sable graveleux
Roc
Altitude
Distance du centre piste

Conclusion

Key facts

- Currently, runways are mostly affected along their sides due to snow and water accumulations along enbankments.
- Some settlements in the central part of runways are due to limited water flow and seepage channels.
- With climate warming, the deepening of the active layer under the runways will generate differential settlements over time, requiring maintenance.
- Controling snow accumulations along runways and preventing water infiltration are prioritary in current interventions.


Thank you very much!
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