The development of Kangiqsualujjuaq and the threat of snow avalanches in a permafrost degradation context, Nunavik, Canada

Armelle Decaulne, Najat Bhiry, Janie Faucher-Roy, Clara Pelletier Boily

Espace populations sociétés
Space populations societies

2020/3-2021/1 | 2021
Espaces et sociétés arctiques

The development of Kangiqsualujjuaq and the threat of snow avalanches in a permafrost degradation context, Nunavik, Canada

Le développement de Kangiqsualujjuaq et la menace des avalanches de neige dans un contexte de dégradation du permafrost, Nunavik, Canada

Armelle Decaulne, Najat Bhiry, Janie Faucher-Roy and Clara Pelletier Boily

Electronic version
URL: http://journals.openedition.org/eps/10497
DOI: 10.4000/eps.10497
ISSN: 2104-3752

Publisher
Université des Sciences et Technologies de Lille

The development of Kangiqsualujjuaq and the threat of snow avalanches in a permafrost degradation context, Nunavik, Canada

Le développement de Kangiqsualujjuaq et la menace des avalanches de neige dans un contexte de dégradation du permafrost, Nunavik, Canada

Armelle Decaulne, Najat Bhiry, Janie Faucher-Roy and Clara Pelletier Boily

AUTHOR'S NOTE

This work is supported by the French National Research Agency through the Labex DRIIHM program « Investissements d'avenir » referenced ANR-11-LABX-0010. It is also supported by the French Polar institute IPEV (funding #1148 DeSiGN), and the Natural Sciences and Engineering Research Council of Canada (NSERC). We also thank the council of Kangiqsualujjuaq and the inhabitants of the village, our partners at the Kativik Regional Government and the Makivik corporation for their valuable collaboration and the Centre d'études nordiques for logistical support. We also thank Emmanuel L'Hérault for providing elevation data to build up the longitudinal profiles.

Introduction

1 In Nunavik, few studies have focused on slope processes (snow avalanches, landslides, rockslides, etc.). Indeed, according to Germain [2016], Nunavik has favourable environmental conditions for gravity movements : steep, bare slopes heavily weathered by strong periglacial conditions, snowfall and strong winds. Recent studies have shown

that gravitational processes began in Nunavik about 4600 years ago due to the release of pressure accumulated in rock material during the glaciation period [Decaulne *et al.*, 2018, Bhiry *et al.*, 2019]. In the Umiujaq region, southwest of Nunavik, gravitational movements pose a significant risk to the community on the road to Lake Tasiujaq, which passes below the steep high slopes of the Hudsonian cuestas [Veilleux *et al.*, 2019]. Several snow-avalanche events occurred in the past, in Inukjuak, Ivujivik, Kangirsuk, Kangiqsujuaq, Quaqtaq and Salluit [Lied and Domaas, 2000]. However, the deadly snow avalanche that occurred on the night of December 31st, 1998-January 1st, 1999 in Kangiqsualujjuaq, located in north-eastern Nunavik (Figure 1) [Bérubé, 2000], highlighted the level of risk. At this time, the inhabitants were gathered to celebrate New Year's Eve in the school gymnasium. The gymnasium was located within the deposit zone of a short snow-avalanche path. The memory of this event is locally long-lasting. However the accurate perception of hazard is impeded by the lack of systematic data collection regarding slope activity in locations where hazard could easily shift to risk due to the vulnerability of settlements or short transportation corridors around settlements. In the 1980s and 1990s, at least four snow avalanches occurred in Kangiqsualujjuaq before the 1999 dreadful snow avalanche.

Figure 1 – Location map of Nunavik (A) in Northern Quebec (B) and Kangiqsualujjuaq surroundings (C), with National Parks in grey shade; a view of the village taken from the east-north-east at low tide (D).

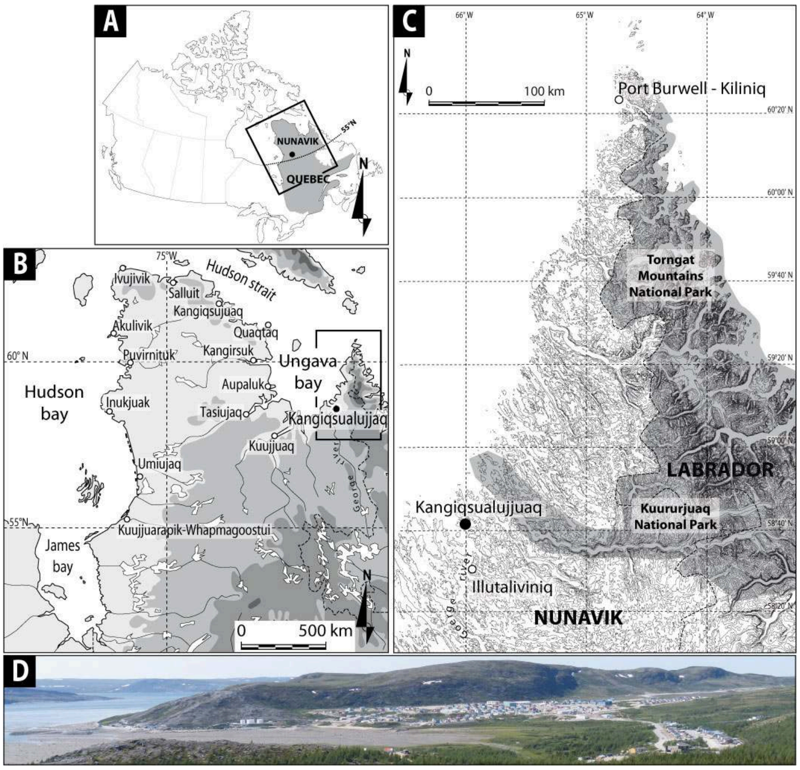


Photo A. Decaulne, 2018.

2 Following the 1999 catastrophic snow avalanche, the spatial organization of the village changed significantly, starting with the relocation of several buildings (school, church, and a Co-op store) and houses. The erection of a 150-m long and 5-m high protection wall at the base of the slope was carried out on decision of the Ministry of Public Security, and a 100-m exclusion zone was established between the foot of the slope and

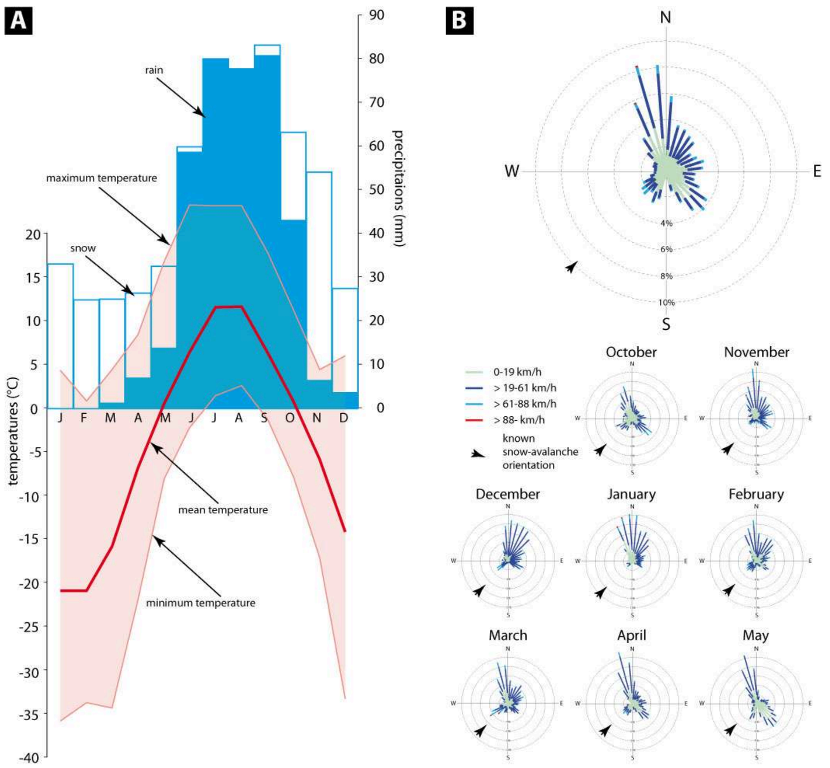
the village [Schaerer *et al.*, 1999]. The subsequent development of Kangiqsualujjuaq in response to its population growth must take into account the permafrost degradation on the land on which it is built. The main objective of this paper is to examine how a single snow-avalanche event caused the breakup of the original structure of Kangiqsualujjuaq village, far from its historical centre, in a context of demographic growth. To achieve this goal we conducted a literature review, a diachronic analysis of aerial photographs and our own geomorphologic observations in the field.

Prone snow-avalanche weather conditions in Kangiqsualujjuaq valley

3 Snow avalanches are a natural phenomenon resulting from the combination of slopes and snow, the latter being destabilized and moving downslope under different conditions. The hazard is well known in Canada, where several recreation, transportation, property and resource industries are at threat [Stethem *et al.*, 2003]. In Nunavik, several villages and village surroundings are at risk, although the issue lacks in-depth studies, as several of the communities gather favourable terrains, *i.e.*, slopes with inclination over 10-15° [Lied and Doomas, 2000], coupled with favourable weather conditions (temperature, precipitation and wind). The issue is exacerbated by weather conditions conducive to the occurrence of avalanches such as strong winds, snowfall and bare slopes heavily weathered by heavy periglacial activity ; however scarce and only recent weather data are available due to several newly installed and partially operating weather stations. The closest precipitation and air temperature measurements from Kuujjuaq indicate the clear polar climate (Figure 2A), with seven months recording a negative mean temperature (period 2006-2015, from Aubé-Michaud *et al.*, 2017), and eight months with exclusive or notable snow input ; mean annual air temperature is -5.2°C (1982-2012), with means of +9.5°C in July and -21.1°C in January. Annual precipitation is approximately 460 mm, with 45 % falling as snow. In Kangiqsualujjuaq, the SILA station of the Centre d'études Nordiques (CEN) indicates that winds come mostly from the north-north-west (Figure 2B) at an average speed of 19 km/h (during winter months, recording snowfall, the wind orientation varies from NNW to NNE). In general, the average daily wind speed is less than 49 km/h (99.8 % of the time), but hourly peaks of more than 50 km/h have been observed during the winter months [Aubé Michaud *et al.*, 2017].

4 In the analysis of snow-avalanche hazards and associated risks, the knowledge of past events is highly depending on the occupation period and clear account of events (dates, location of the path, type of snow, runout distance, etc) [McClung and Schaerer, 1993 ; Stethem et al, 2003], enabling differentiating the situation of risk from punctual catastrophic events [Dauphiné and Provitolo, 2003] ; in Kangiqsualujjuaq valley, human occupation has been only temporary before the settlement, the precise camp sites being not precisely known ; the village further recorded a constant demographic growth since its establishment. Wind has a strong role in the gathering of the snow that will be forming the snow avalanche : in Kangiqsualujjuaq, none of the known snow-avalanche events originate from the usual NNW direction, but from the WSW to SW unusual blizzards (Figure 2B).

Figure 2 – Climate data. A: temperature and precipitation in Kuujjuaq, from 2006-2015; B: origin and mean speed of daily winds in Kangiqsualujjuaq CEN station from 2005-2008 and winter months details (modified from Aubé Michaud et al., 2017).



A recent village with a growing population

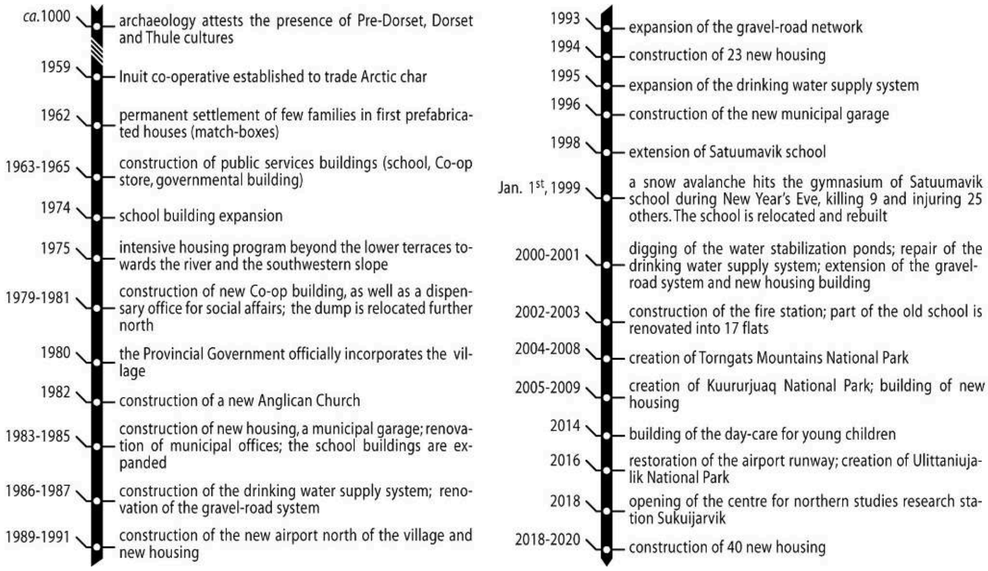
A historical perspective of Kangiqsualujjuaq

5 Kangiqsualujjuaq, which means “very large Bay”, is the easternmost village in Nunavik and located in Akilasakallak Cove on the George River (Figure 1). Kangiqsualujjuaq was funded on a land that has been previously occupied by Pre-Dorset, Dorset and then by Thule peoples, as indicated by the archeological remains (Avataq Cultural Institute 2011). Kangiqsualujjuaq began as a series of temporary trading establishments along the George River estuary and the shore of the Ungava bay (Archives of Manitoba). The closest outspost was the Hudson’s Bay Company outpost established in 1838 in the Illutaliviniq region. This outpost was named Fort Severight, and was located about 15 km south of Kangiqsualujjuaq. The Hudson Bay Company operated there from the first part of the 19th century to the mid 20th century as a salmon and seal fishery. Over 300 km north, along the shore of the Ungava Bay, the long lasting settlements of Port Burwell/Kiliniq has been occupied as a trading post or other posts from the end of the 19th century to late 1970s.

6 The present-day location of Kangiqsualujjuaq was established in 1959 (Figure 3), when local Inuit created one of the first co-operatives in Northern Quebec to trade Arctic char with southern Canada (Archives of Manitoba). The site and its surroundings have long been occupied by temporary camps, as it is remembered by Tivi Etok from when he was a young boy [Weetaluktuk and Bryant, 2008]. However it is unknown whether these were summer or winter camps; these camps never rose to the level of a “village”,

while Killiniq was clearly identified as a large village well located on the migration route of marine mammals known by Inuit ancestors, "*the oldest continuously inhabited site*" [Tivi Etok in Weetaluktuk and Bryant, 2008] (Figure 1c). No evidence of continuous occupation of Kangiqsualujjuaq territory is found prior to 1959. From 1959 on, constructions were uninterrupted and included several public services (schools, government buildings, a health dispensary, a water supply system, a church, a municipal garage, a dump, gravel roads, a runway, sport infrastructures, etc) and numerous houses. Nowadays, Kangiqsualujjuaq is the starting point for visitors to the northeasternmost Canadian National Parks (Torngats Mountains and Kuururjuaq) and home of the park headquarters. A research station has also recently been established in the village (2018), managed by the University Laval and the community of Kangiqsualujjuaq.

Figure 3 – Key dates in the history of Kangiqsualujjuaq (modified from Gerardin et al., 2015 and MAMOT 2015)



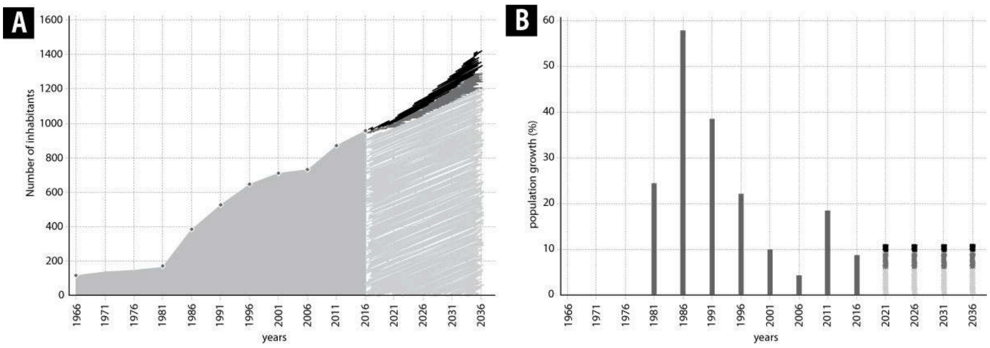
A demographic perspective on Kangiqsualujjuaq

7 The expansion of the village responds to the population growth that jumped from 149 to 942 inhabitants from 1981 to 2016, according to Statistics Canada. According to Charbonneau *et al.* (2019) Inuit Northern Quebec gathers the largest proportion of people under 19 years old (41.4%), with a mean age in 2018 of 27.7 years old (26.2 in Kangiqsualujjuaq in 2016). The Kativik Regional Administration area, which encompasses the entire northern portion of the 55th parallel (Nunavik) with the exception of the Whapmagoostui Cree lands, records a significant demographic growth, with +16% from 2016 and 2018. As in most of the villages in Northern Quebec, the population growth in Kangiqsualujjuaq has been sustained over the last decades, increasing to 632% of population since 1968, when the village started to develop, and 245% since the village has been officially established in 1980 (from 383 to 942 inhabitants - Figure 4A). Population data are verified only from 1981, after the village has been formally integrated within the Quebec Provincial Government. The demographic growth projections are calculated according to three scenarios, based on the previous incremental trends observed through official census within the Kativik

Regional Administration area. In Kangiqsualujjuaq, the population evolution has not been steady, although it has been always positive: the village never lost inhabitants, and its population grew from +3.5 to 58% from 1966-2016 (Figure 4B). The greatest increase in population occurred after the village gained its official status in 1980. Therefore, the projections indicate +6.91%, +9.13% and +11.82% growth based on regional baselines, the 1996-2015 average or the 2006-2015 average respectively [in Gerardin *et al.*, 2015].

8 Such a demographic boom in a Nordic village has led to the expansion of the territory used for housing, service buildings and transport infrastructures.

Figure 4 – Demographics in Kangiqsualujjuaq, with raw data and 2036 projections (A) and population growth (B).



On both graphs, the three demographic scenarios are shown with hatched grey, light grey and dark grey colors; the census began only in 1981; Savoie (2013) mentions 120 inhabitants in 1967.

Based on Statistics Canada and Gerardin et al. (2015).

A spatial perspective of Kangiqsualujjuaq

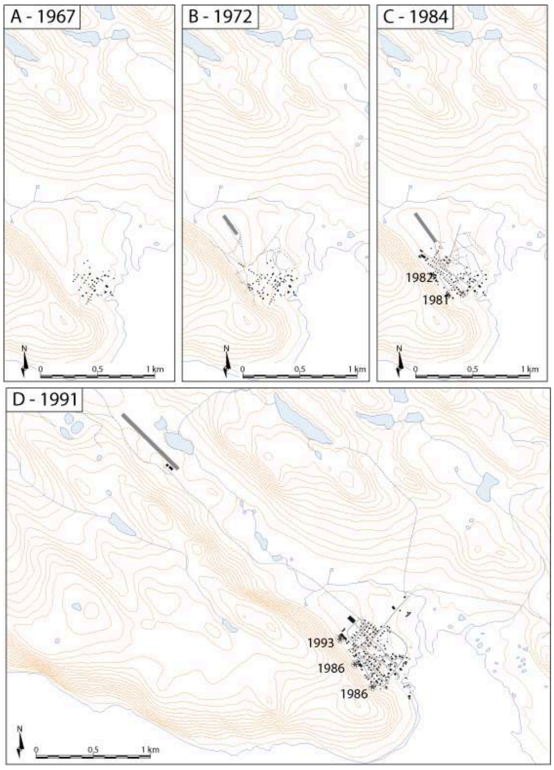
9 As mentioned earlier, permanent settlement in Kangiqsualujjuaq, at its location by Akilasakallak cove, on the eastern bank of George River estuary, started with the establishment of a Co-op, in 1959. Only two families were settled there at that time [Weetaluktuk and Bryant, 2008], and peoples from small camps nearby moved there to form the beginning of a community. At that time, the village was composed of tents and only one log cabin. The first permanent buildings, such as the saw mill and the school, where erected on the lower land; prefabricated houses were erected from 1962 on the first terraces, as well as the church, as shown on Figure 5A. This location is sheltered from the prevailing winds coming from the southeast to the northwest (Figure 2B; Germain, 2016). In 1972 (Figure 5B), the village became more organized, with a clearer separation between houses and utility buildings. The newer development at that time was closer to the shore. The village grew below the mountain slope on the right bank of the river that drains the valley with more houses, stores, a Co-op and municipal office (1984, Figure 5C). From that point on, development occurred at the bottom of the valley (1991, Figure 5D) and further down the valley, with the extension of the school that had been previously relocated by the slope previously, and the construction of the new airport at its present location. The village then extended further within the valley, towards the north-west, and occupies the lower terraces north of Akilasakallak cove (2002, Figure 5E). This is the location for the new municipal garage and the drinking water supply. Figure 5F-2015 shows the further development on the western part of the

village along the south-east facing slope, including new housing, the police building and the day-care building. The road system has significantly developed, including long portions of paved streets within the village and mixed gravel and paved roads towards the airport. There are also offset facilities such as the used-water basins and the dump.

10 From the beginning of the settlement in the 1960s to the present days, the spatial extension of the village has been significant, multiplying the number of buildings (residential and services) from few scattered buildings to become a village, with numerous streets and cross-roads. The original valley snout has been extensively used to develop the village over a greater area, by the northwestern bank of the cove. Later, the housing programs spread into the remaining areas in the valley, further from the cove.

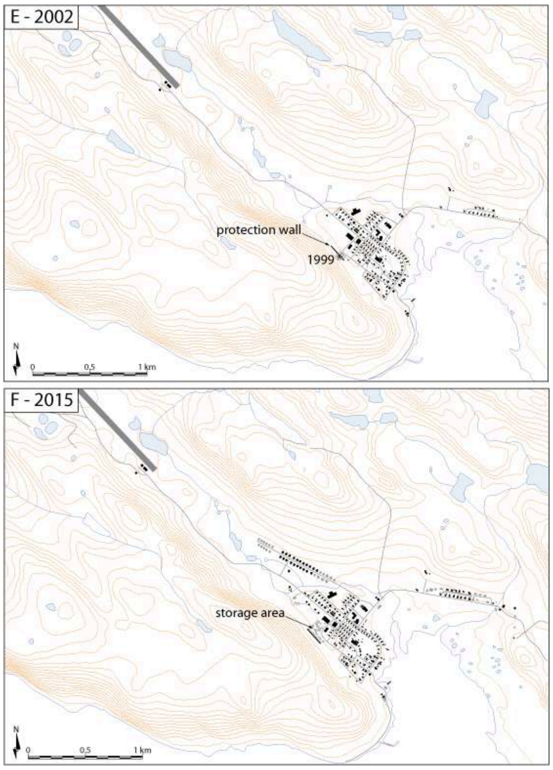
11 With the opening of three National Parks in the surroundings of Kangiqsualujjuaq over the last 10 to 15 years (Torngats Mountains to the North, Kuururjuaq to the west and Ulittaniujalik by Pyramid Peak 115 km to the south), the village acquired the National Parks office and became the official gateway. Kangiqsualujjuaq is therefore welcoming many tourists to the area, and requires additional infrastructures (transportation, lodging, activities).

Figure 5 – The spatial expansion of Kangiqsualujjuaq from 1967 to 2015, mapped from available aerial photographs.



Dates and further runout of snow avalanches are marked with an asterisk.

Figure 5 (following) - The spatial expansion of Kangiqsualujjuaq from 1967 to 2015, mapped from available aerial photographs.



Dates and further runout of snow avalanches are marked with an asterisk, as well as the position of the 150 m long by 5 m high protection wall erected behind the former school and gymnasium, now used as a storage area. Buildings in grey on the F-2015 map are those build between 2015 and 2019.

The impact of the 1999 snow avalanche on the spatial distribution of the village

12 The catastrophic avalanche hit the gymnasium in Kangiqsualujjuaq in the New Year's Eve 1999 at 01:45 [Stethem *et al.*, 2003; Germain, 2016]. To celebrate the New Year, over 100 of the people were gathered in the gymnasium, which was located in the westernmost part of the school [Campbell *et al.*, 2007]. At this time, the school and its gymnasium were the largest building close to the north-east facing slope (Figure 5D). The distance between the slope and the back of the gymnasium building was short, not exceeding 40 m [Stethem *et al.*, 2003]. The snow passed through the gymnasium backwall by an additional 35 m, reaching a runout of approximately 75 m and extended along both sides of the gymnasium. It attained a width of 130 m in the deposited area. Due to the convex slope at the top of the rockwall (Figure 6), the slight leeward depression facilitated the gathering of blown snow in the windy environment, forming snow cornices [Germain and Martin, 2011]. A 220 m wide snow avalanche, about 4 m thick, detached from a height of about 110 m a.s.l. on a slope 38° steep [Lied and Doomas, 2000; Stethem *et al.*, 2003]. The southwest walls of the gymnasium (on which the main door was located), was breached with an impact pressure of about 10 kPa [Schaerer *et al.*, 1999]. A blizzard had been in the area for several hours with western winds from 25-40 km/h following several days of blowing snow [Schaerer *et al.*, 1999]; such winds were uncommon (Figure 2). The death toll was 9 dead (including 5 children)

with 25 people injured (about 1.5% and 4% of the village population at that time respectively).

Figure 6 – Kangiqsualujjuaq in 2019.

In black, a schematic reconstruction of the location of former buildings, which today corresponds to the exclusion zone, and known damaged buildings by snow-avalanche events prior to 1999; the white dashed lines represent the departure zones of those snow avalanches.

Photo: A. Decaulne.

13 Previously, other snow-avalanche events had been observed (Figure 6A), but these did not cause such extensive damage and harm to people. The dates for these events are not precise [Stethem *et al.*, 1999; Hétu, 2001]:

- the "small store" was hit in March or April 1981 or 1982, catching one person who was not injured; the runout of the snow-avalanche from the foot of the slope was approximately 20 m;
- the back wall of the Co-op store was hit twice, in March or April 1982, 1984 or 1986: canoes were damaged in one of the two snow avalanches, and one person was caught in the other one, without sustaining an injury; the runout distance to the Co-op was about 20 m;
- the back wall of the Youth Centre was hit in March or April 1984 or 1986; no one was injured, although the runout distance to the building is the shortest, at only 14 m;
- the back wall of the school gymnasium was hit in March 1993, and the steps leading to the door were buried under 1.5 m of snow; two people were buried but extracted alive, although one was injured; the runout distance was 40 m.

14 None of these events had been formally reported, as the damage they caused was limited. After the 1993 event, however, the back of the school was considered unsafe by some of the inhabitants and an expert [Hétu, 2001] recommended that the snow cover be stabilized at the source-area and that the backdoor of the gymnasium be sealed.

15 Snow-avalanche deposits were observed at the foot of the slope in February 2000, during experts visit [Lied and Doomas, 2000], local people saying that such snow avalanches, however qualified as "not important" as provoking no damage, do happen yearly.

16 The devastating avalanche event in 1999 prompted the investigation of snow avalanches, highlighted the previous events that had not been formally reported, and prompted the Quebec Ministry of Public Safety to consult with various experts. It was recommended that the exclusion zone be further extended from 75 to 100 m [Guilbault, 2018]. This decision required the relocation of over 40 buildings, which mainly included houses but also a few business and services (a school, Co-op, church, etc.). The affected area also represented about 1/5 of the surface of the village at that time, requiring the

designation of new building locations along Akilasakallak cove and the northern part of the valley (Figures 5 E-G and 6).

Challenges ahead: conflicts between human needs and natural constrains

17 As the population of Kangiqsualujjuaq continues to grow, although at a slower pace that it did during the end of the 20th century, the need for housing also grows. The core of the village is already densely built. The main issue is to determine the location for new housing developments, along with associated infrastructure, such as transportation. The topography of the valley certainly represents a constraint, as slopes over 35° are prone to release slab snow avalanches of all sizes [McClung and Schaerer, 1993]. Under specific snow conditions, when large amounts of windblown snow are falling over ice crusts formed into the previous snowpack, or during sudden thaw, slopes from 10 to 25° are prone to releasing infrequent slab avalanches, or loose wet snow avalanches. Slush flows can also be released on slopes of 5 to 25° [McClung and Schaerer, 1993]. A wet snow avalanche will decelerate on slopes with a gradient lower than 10°. Rockfall cannot be excluded either, as observed during field work (Figure 7). Regarding the possible return period of the largest potential snow-avalanche event, the gathering of accurate data over 200 years at a specific location would be required to be 90% confident that a 100-year return period event had been documented within the chronology [McClung and Schaerer, 1993]. This 200-years snow-avalanche history is not yet recorded in Kangiqsualujjuaq. Therefore, all areas along the southeastern slope are potentially at risk, and the greater exclusion zone established after the 1999 fatal snow avalanche is fully justified; however, the road to the airport lies very close to the length of the slope west of the village. Furthermore, the new housing development located along the gentler northwestern slope could also be affected by wet and slush snow avalanches as the slope gradients there are rarely below 10°.

18 The village is also located within a zone of abundant discontinuous permafrost, at the edge of the continuous permafrost zone [Allard *et al.*, 2012]. The permafrost distribution and thickness, as well as the thickness of the active layer, vary considerably depending on the grain size and type of superficial sediments, snow-cover thickness, hydrological conditions and vegetation. In addition some zones of the valley are poorly drained (Figure 7).

19 Globally, the territory of the municipality of Kangiqsualujjuaq can be divided into three sectors according to its superficial sediment/substrate and topography (Figure 6) and associated reaction to permafrost thaw:

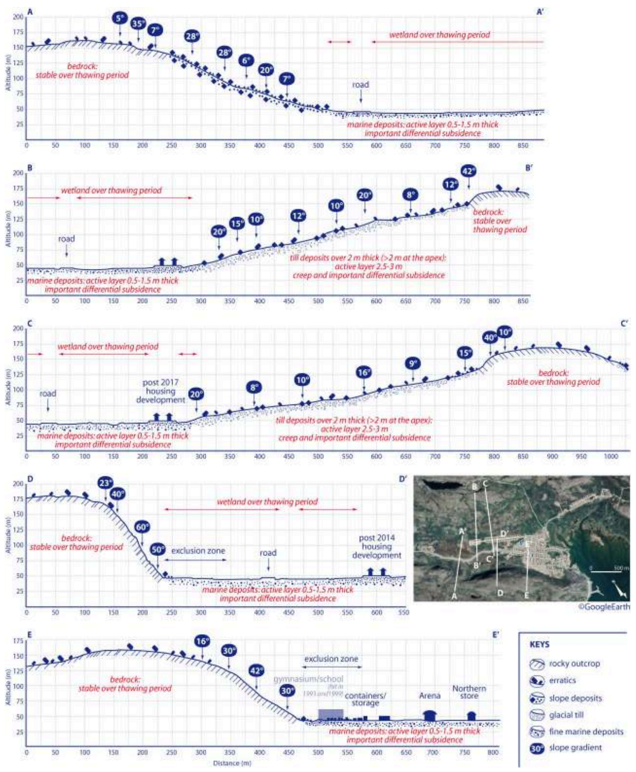
- bedrock outcrops, which can be divided into summit areas and slopes. These areas are exposed to dominant winds or the slope gradient prevents human occupation and infrastructure setting such as transportation corridors. The active layer is 4.5 to 6 m thick; joints and cracks may contain ice. The rockmass may be unstable superficially where the slope gradient is steep [Aubé-Michaud *et al.*, 2017].
- marine deposits, composed of silt to fine sand, occupy the bottom of the valley. The active layer reaches 0.5 to 1.5 m; lots of segregation ice is present. The sediment subsides easily. In the center of the valley, between the airport and the village, there are abundant ice-rich poorly drained silt deposits. These thaw-sensitive deposits are unsuitable to construction,

which limits the expansion of buildings in this area. These deposits of sandy fine sand are sensitive to thaw, creating wetland that are fed by surface water during frost-free seasons. Unstable terrains during the thawing period are evidenced by the thermokarstic subsidence that affects and deforms the road. Furthermore, as in many places in the valley, several seasonal ice-core mounds were observed along the airport access road in a depressed area, in a fine sand deposit. Power poles along the road have been damaged because of this [L'Hérault *et al.*, 2014; Aubé-Michaud *et al.*, 2017].

- glacial till, over 2 m thick in the lower parts, and less than 2 m thick at the apex, on the neighboring gentle slopes, are mostly present on the northern slope of the valley. The active layer is 2.5 to 3 m thick. This sediment is creeping and locally subsiding, *i.e.*, unstable during the thawing period [Aubé-Michaud *et al.*, 2017].

In such topographic and permafrost conditions, very little terrain is suitable for construction (Figure 7). The bedrock is made of granitic gneiss and would support buildings where the topography is not too uneven; there, the active layer has little effect on the surface stability. Sand and gravel deposits about 2 m thick over the bedrock could also be suitable, as the ice volume within such material remains below 10 m. Gravel and sand deposits over 2 m thick are also well drained, inhibiting important ice content, even with an active layer 2.5-3 m thick. Therefore, the most extensive areas suitable for further construction that could possibly support housing developments are (i) the site beside Akilasakallak cove where houses were transferred from the snow-avalanche exclusion zone after the 1999 avalanche, and (ii) the site beyond the airport. The first area mentioned still has some space left for new construction; the second one is located far from the village core, but already benefits from transportation infrastructures since part of it is used as a sand and gravel quarry. Other surfaces are not suitable for sustained development, requiring post-construction building adjustments and infrastructure maintenance. With reference to Figure 8, we observe that the whole valley bottom is excluded from the prone building surface, as marine deposits are unstable during the thawing period.

Figure 7 – Cross profiles of Kangiqsualujjuaq valley.



From these profiles, one can observe the distribution of the three main surfaces within the valley, i.e., bedrock, glacial till and fine marine deposits. The indications regarding slope gradients also provide information on the potential slope processes, such as snow avalanches, rockfall and creep.

Elevation data extracted from LiDAR 2010, ministère de l'Énergie et des Ressources naturelles.

Figure 8 – Location of the suitable construction areas on surfaces where permafrost thawing and active layer fluctuations have little effect on the stability of the surface, away from active slope processes areas (modified from Aubé-Michaud et al., 2017).

Background support from GoogleEarth (image from August 2019).

Conclusions

21 The topography and permafrost situation in Kangiqsualujjuaq has forced the growing community to consider adaptive measures to reduce the risk posed to the population and to local infrastructures. A large part of the lowland area, at the bottom of the valley and along the coastline includes terrains that are unsuitable for construction. However, this is where most of the village is located and where the recent development has occurred. Snow-avalanche events forced the relocation of part of the village, and permafrost thawing associated with the deepening of the active layer required significant engineering design to sustain drainage and building stability. Areas suitable for construction are seldom found at low altitude and are mostly located west of the pass where the airport is located. There is greater exposure to wind here and the distance to the center of the village (and to facilities such as the school, medical center, stores, and municipal services) is much longer. Northern stakeholders have important choices to make, in collaboration with the residents (local observers) and scientists, about how to manage slope processes and respond to surface surveys that identify permafrost conditions at the local scale.

BIBLIOGRAPHY

ALLARD M., LEMAY M., BARRETTE C., L'HÉRAULT E., SARRAZIN D., 2012, Permafrost and climate change in Nunavik and Nunatsiavut: Importance for municipal and transportation infrastructures. In Allard M. and Lemay M. (Eds): *Nunavik and Nunatsiavut: From science to policy. An Integrated Regional Impact Study (IRIS) of climate change and modernization*. ArcticNet Inc., Québec, Canada, pp. 171-197.

AUBE-MICHAUD S., ALLARD M., L'HERAULTE., MATHON-DUFOUR V., 2017, *Identification des risques actuels et appréhendés sur le territoire des communautés du Nunavik en fonction des changements climatiques –phase 1 : Document de synthèse, communauté de Kangiqsualujjuaq.* Rapport final réalisé pour le compte du Ministère de la Sécurité publique (Gouvernement du Québec), Centre d'études nordiques, Université Laval, 68 p.

ARCHIVES OF MANITOBA, http://pam.minisisinc.com/scripts/mwimain.dll/144/PAM_AUTHORITY/AUTH_DESC_DET_REP/SISN%20115?sessionsearch

AVATAQ CULTURAL INSTITUTE, 2011, http://www.avataq.qc.ca/en/Institute/Departments/Archaeology/Discovering-Archaeology/Arctic-Chronology.

BÉRUBÉ J., 2000, *Rapport d'enquête publique suite à l'avalanche de 1999 à Kangiqsualujjuaq.* Rapport du bureau du coroner, 66 p.

BHIRY N., DECAULNE A., BOURGON-DESROCHES M., 2019, Development of a subarctic peatland linked to slope dynamics at Wiyasakami Lake (Nunavik, Canada). *The Holocene*, 29, 9, pp. 1459-1467.

CAMPBELL C., BAKERMANS L., JAMIESON B., STETHEM C., 2007, *Current and future snow avalanche threats and mitigation measures in Canada*. Canadian Avalanche Center, 109 p.

CHARBONNEAU A.B., ST-AMOUR M., ANDRE D., GIRARD C., 2019, *La population des régions administratives, des MRC et des municipalités du Québec en 2018.* Institut de la Statistique du Québec, Coup d'œil sociodémographique, n° 69, 57 p.

DAUPHINE A., PROVITOLO D., 2003, *Risques et catastrophes. Observer, spatialiser, comprendre, gérer*. Paris, Armand Colin.

DECAULNE A., BHIRY N., LEBRUN J., VEILLEUX S., SARAZIN D., 2018, Geomorphic evidence of slope dynamics on the Canadian Shield throughout the Holocene – a study from Lac à l'Eau-Claire, western Nunavik. *Ecoscience* 25, pp. 343-357.

GERARDIN T., DUCHAINE T., 2015, *Background report – Kangiqsualujjuaq master plan and zoning bylaw, update*. 45 p.

GERMAIN D., 2016, Snow avalanche hazard assessment and risk management in northern Quebec, Canada. *Natural Hazards* 80, pp. 1303-1321.

GERMAIN D., MARTIN J.-P., 2011, The vulnerability of northern cities to weather-related hazards: case studies from the Province of Quebec, Eastern Canada. In Daniels J.A. (Editor): *Advances in Environmental Research.* Volume 22, Nova Science Publishers, pp. 143-160.

GUILBAULT S., 2018, Kangiqsualujjuaq, mitigating avalanche risk through land-use planning. In Kovacs P., Guilbault S., Darwish L., Comella M. (Eds.). *Cities adapt to extreme weather – celebrating local leadership. Institute for catastrophic loss reduction*, Toronto, Institute for Catastrophic Loss Reduction, pp. 22-25.

HETU B. (2001), Une géomorphologie socialement utile – La question des risques naturels. In Laurin S., Klein J.L., Tardif C. (Eds.). *Géographie et société, vers une géographie citoyenne.* Presses de l'Université du Québec, Sainte-Foy, Canada, pp. 61-92.

L'HERAULT E., ALLARD M., LEMAY M., BARRETTE C., CARBONNEAU A.-S., 2014, *Investigations géotechniques, caractérisation du pergélisol et stratégie d'adaptation dans un contexte de changements climatiques pour la route d'accès et l'aéroport de Kangiqsualujjuaq, Nunavik.* Rapport final, Centre d'études nordiques, Université Laval, Québec, 78 p.

LIED K., DOMAAS U. (2000), *Avalanche hazard assessment in Nunavik and on Côte-Nord*, Québec, Canada. Ministère de la Sécurité publique du Québec, 34 p.

MCCLUNG D., SCHAERER P. (1993), *The Avalanche Handbook.* Seattle, The Mountaineers, 271 p.

MINISTERE DES AFFAIRES MUNICIPALES ET OCCUPATION DU TERRITOIRE (MAMOT) (2015), Répertoire des municipalités (Kangiqsualujjuaq).

SAVOIE D., 2013, Le Nord du Québec. Société d'Habitation du Québec conférence, « les Entretiens sur l'habitat », 8 Octobre 2013, Québec. http://www.habitation.gouv.qc.ca/fileadmin/internet/documents/SHQ/entretien_habitat/2013/Nord_du_Quebec.pdf

SCHAERER P., JAMIESON B., STETHEM C., 1999, *Avalanche hazard mitigation for Kangiqsualujjuaq, Québec.* Technical report, Ministère de la sécurité publique, Gouvernement du Québec, 13 p.

STATISTICS CANADA https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/abpopprof/details/page.cfm ? Lang =F&Geo1 =CSD&Code1 =2499090&Data =Count&SearchText =kangiqsualujjuaq&SearchType =Begins&B1 =All&SEX_ID =1&AGE_ID =1 consulté le 29/01/2020

STETHEM C., JAMIESON B., SCHAERER P., LIVERMAN D., GERMAIN D., WALKER S., 2003, Snow avalanche hazard in Canada – a review. *Natural Hazards,* 28, pp. 487-515.

VEILLEUX S., BHIRY N., DECAULNE A., 2020, Talus slope characterization in Tasiapik Valley (subarctic Québec): evidence of past and present slope processes. *Geomorphology* Doi : 10.1016/j.geomorph.2019.106911

ABSTRACTS

Slope processes are active in the rolling plateau landscapes of Nunavik, Northern Québec, Canada. There are a few short but very steep escarpments in this region. On January 1st, 1999 a powerful snow avalanche struck Kangiqsualujjuaq, one of the 14 Inuit villages in Nunavik. Nine people died and 25 were injured. This village and its surrounding are located within a glacial valley, in a periglacial environment. There is significant population growth, as well as in the other villages in Nunavik. As early as 1999-2000, there was a significant spatial reorganization of the village's infrastructures to avoid the impact of other snow-avalanche events. The main objective of this paper is to examine the village expansion in response to snow-avalanche process and population growth, within an area constrained with permafrost thawing and steep slopes. From naturalist geomorphologic methods, written sources such as archive documents and aerial photographs, the results show that slopes above Kangiqsualujjuaq are prone to release snow avalanches during blizzards from uncommon directions, and that the newly built housing may be at risk in some places, due to the conjunction of snow avalanches and permafrost thawing.

Dans les paysages de plateaux ondulés du Nunavik, au nord du Québec, au Canada, les processus de versant sont actifs. Les escarpements sont rares et courts, mais sont significativement pentus. Le 1er janvier 1999, une avalanche mortelle a touché le village de Kangiqsualujjuaq, l'un des 14 villages du Nunavik ; neuf personnes ont perdu la vie, et 25 ont été blessées. Les expertises déclenchées par cet événement ont mis en lumière au moins quatre avalanches antérieures durant les années 1980-1990. Le village et ses environs sont localisés dans une vallée glaciaire, en environnement périglaciaire, et connaissent une forte pression démographique, comparable à celle des autres villages du Nunavik. Dès 1999-2000, la réorganisation spatiale des infrastructures du village est visible afin d'éviter l'impact d'autres avalanches émanant du même versant. L'objectif de cette contribution est d'examiner la restructuration du village en réponse aux avalanches génératrices de risque dans un contexte de croissance démographique forte, dans une zone contrainte par la fonte du pergélisol et les versants raides. A partir d'une approche géomorphologique naturaliste, de sources écrites, tels les documents d'archive, et de photographies aériennes diachroniques, les résultats montrent d'une part que les versants qui dominent Kangiqsualujjuaq sont favorables au déclenchement d'avalanches durant les blizzards de directions inhabituelles, et d'autre part que les logements récemment construits peuvent dans certains cas se trouver également en situation de risque, en raison de la conjonction des avalanches et de la fonte du pergélisol.

INDEX

Keywords: Nordic village, slopes, active layer, demographic growth, snow avalanches, Canada
Mots-clés: village nordique, versants, couche active, croissance démographique, avalanches, Canada

AUTHORS

ARMELLE DECAULNE

CNRS, laboratoire LETG-Nantes, France, armelle.decaulne@univ-nantes.fr

NAJAT BHIRY

Université Laval, Département de Géographie et Centre d'études nordiques, Québec, Canada, najat.bhiry@cen.ulaval.ca

JANIE FAUCHER-ROY

Université Laval, Département d'Anthropologie, Québec, Canada, janie.faucher-roy@ulaval.ca

CLARA PELLETIER BOILY

Université Laval, Département de Géographie, Québec, Canada, clara.pelletier-boily@ulaval.ca