ACKNOWLEDGMENTS

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REFERENCES

Allard, M., Doyon, J., Mathon-Dufour, V., LeBlanc, A.-M., L'Hérault, E., Mate, D., Oldenborger, G.A., and Sladen, W.E., 2012. Surficial geology, Iqaluit, Nunavut; Geological Survey of Canada, Canadian Geoscience Map 64 (preliminary version), scale 1:15 000. doi:10.4095/289603

Nolan, M. and Fatland, D.R., 2003. Penetration Depth as a DInSAR Observable and Proxy for Soil Moisture. IEEE Transaction on Geoscience and remote sensing, Vol. 41, No. 3: 532–537.

Nixon, F.M. and Taylor, A.E., 1994. Active layer monitoring in natural environments, Mackenzie Valley, Northwest Territories. Geological Survey of Canada, Current Research, Vol. 1994-B, pp. 27–34.

Rabus, B., Wehn, H., and Nolan, M., 2010. The Importance of Soil Moisture and Soil Structure for InSAR Phase and Backscatter, as Determined by FDTD Modeling. IEEE Transactions on Geoscience and Remote Sensing, Vol. 48, No. 5: 2412–2429.

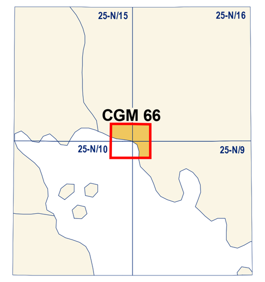
Short, N., Brisco, B., Couture, N., Pollard, W., Murnaghan, K., and Budkewitsch, P., 2011. A Comparison of TerraSAR-X, RADARSAT-2 and ALOS-PALSAR Interferometry for Monitoring Permafrost Environments, Case Study from Herschel Island, Canada. Remote Sensing of Environment, 115:3491–3506. doi:10.1016/j.rse.2011.08.012

Abstract

This map shows the spatial distribution of the relative ground surface displacement between the major terrain units during one summer in the area of Iqaluit. The ground displacement was derived using interferometric synthetic aperture radar (InSAR) data for the summer of 2011. Stable ground represents locations where either no vertical change was calculated or where displacement was within the expected range of error (± 0.5 cm). Very low, low, and moderate downward displacement represents surface lowering on the order of 0.5 to 2, 2 to 4.5, and 4.5 to 8.5 cm, respectively. Upward displacement represents a surface rise of 0.5 to 1.5 cm. Areas of no data result from a loss of interferometric coherence. These are typically water and other relatively smooth surfaces from which there is no radar return, or where there has been significant ground surface disturbance and the radar returns cannot be correlated. The InSAR results correspond well with the expected displacement associated with the characteristics of the major terrain units. The displacement reflects seasonal settlement caused by thawing of ice in the active layer or in the near-surface permafrost.

Résumé

Cette carte montre la distribution spatiale et relative, entre les différentes unités de terrain, des déplacements à la surface du sol au cours d'un été pour la région d'Iqaluit. Le déplacement à la surface du sol a été obtenu en utilisant les données de l'interférométrie radar à ouverture synthétique (InSAR) de l'été 2011. Un sol stable représente une zone où il n'y a pas de changement verticale dans le déplacement de la surface ou là où le déplacement est compris à l'intérieur de la marge d'erreur (± 0,5 cm). Des déplacements vers le bas très faibles, faibles et modérés représentent des diminutions de la surface d'élévation de l'ordre de 0,5 à 2, 2 à 4,5 et 4,5 à 8,5 cm respectivement. Un déplacement vers le haut représente l'augmentation de la surface d'élévation de 0,5 à 1,5 cm. Les zones sans données sont le résultat d'une perte de cohérence interférométrique. Ces zones sont typiquement les étendues d'eau et les surfaces asphaltées à partir desquelles il n'y a pas de réflexion radar ainsi que les zones où la perturbation de la surface du sol est importante. Dans ce cas, la réflexion radar ne peut être corrélée. Une bonne corrélation existe entre les données InSAR et les déplacements qui sont susceptibles de survenir selon la connaissance des caractéristiques des principales unités de terrain. Le déplacement est causé par le tassement au dégel du mollisol ou du pergélisol riche en glace près de la surface.



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City of Iqaluit.
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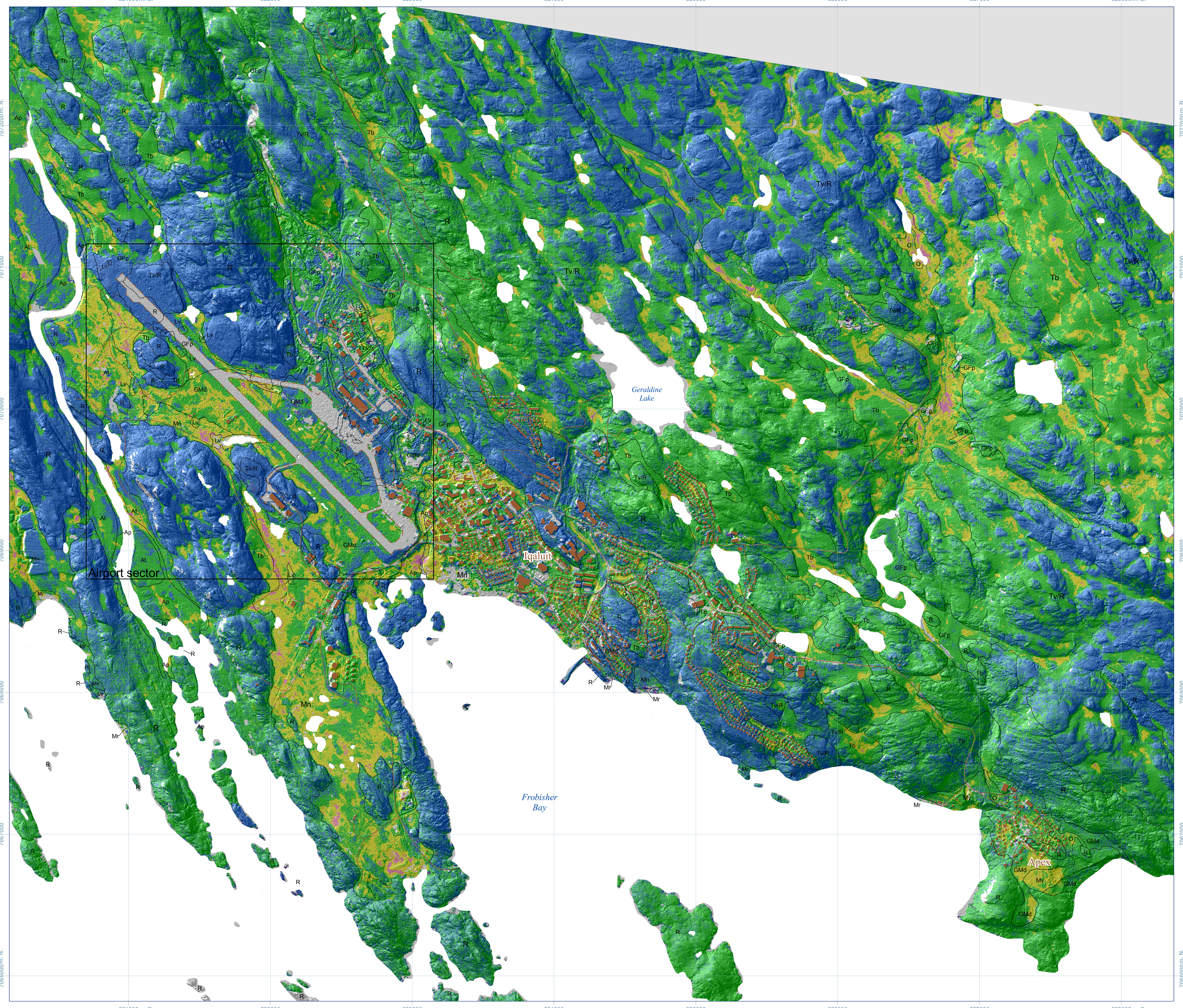
CANADIAN GEOSCIENCE MAP 66
(preliminary version)
SEASONAL SURFACE DISPLACEMENT DERIVED FROM INSAR
IQALUIT
Nunavut
1:15 000



Relative surface displacement

- Upward displacement (+0.5 to 1.5 cm)
- Stable (+0.5 to -0.5 cm)
- Very low downward displacement (-0.5 to -2 cm)
- Low downward displacement (-2 to -4.5 cm)
- Moderate downward displacement (-4.5 to -8.5 cm)
- Loss of InSAR coherence.
- Ap — Geological contacts and label unit, for definition of the geological units below, *see* Canadian Geoscience Map 64 (Allard et al., 2012).

Ap	Alluvial floodplain sediments
At	Alluvial terraced sediments
GFp	Glaciofluvial subaerial outwash plain
GFr	Glaciofluvial esker deposits
GMd	Glaciomarine delta
Lv	Lacustrine veneer
Mn	Littoral and nearshore sediments
Mr	Littoral and nearshore sediments deposited as beaches
Mv	Marine veneer
O	Undifferientiated organic deposits
R	Bedrock
Tb	Till blanket
Tv	Till veneer

▲ Thaw tube location

FIELD OBSERVATIONS

Soil moisture near the surface and ground settlement measurements were taken to validate the range of InSAR detected movement. Soil moisture may affect the penetration depth of a radar wave and hence the InSAR measurements (Nolan and Fatland, 2003). A radar wave may penetrate a dry soil, reflecting off the dry/wet interface; this can result in the displacement signal representing the movement of the moisture front rather than surface displacement. To account for the influence of soil moisture, volumetric moisture contents were measured at the end of July 2011 at two thaw tube sites (T1 and T2, Table 1) as close to the ground surface as possible (5 cm depth). For wet soils, i.e. volumetric water content above 30%, fluctuations in water content do not affect the penetration depth of the radar wave (Nolan and Fatland, 2003). Results show that the soil moisture content at T1 (88%) is high enough to preclude penetration of the radar wave. Site T2 is drier (15%) and might experience some penetration. While the relative dryness of site T2 may be problematic it is highly probable that both sites remain respectively wet (T1) and dry (T2) throughout the summer (Figures 1 and 2), with no significant volumetric water content changes with time for site T2. According to the modelled example of Rabus et al. (2010), the penetration induced by a soil with air-voids and soil moisture gradients varying below 30% should fall within our estimated margin of error for the InSAR measurement (± 0.5 cm). Therefore, soil moisture changes do not appear to be a significant factor influencing the interpretation of these InSAR results.

Site	Volumetric water content measured at a depth of 5 cm (%)[1]	Thaw tube: Observed period	Thaw tube: Maximum settlement (cm)	InSAR: Observed period	InSAR: Maximum displacement (cm)
T1	88	~June 3[2] – Sept 26	-11.8	June 22 – Sept 26	-5.1
T2	15	~May 25[2] – Sept 26	-1.9	June 22 – Sept 26	-0.6

Table 1. Volumetric water content near the ground surface and ground settlement measurements at the two thaw tube sites.

[1] Volumetric water content was measured using a Delta-T Devices ML2x ThetaProbe soil moisture sensor.
[2] First day of ground surface thawing based on ground temperature data.

Thaw tubes, located in poorly drained marine sediments (T1) and in well drained glaciomarine deposits (T2), indicated settlement values of -11.8 and -1.9 cm, respectively, between the beginning of ground surface thawing and the end of September (Table 1). These values are higher than those calculated from the InSAR data. This may be explained by the fact that ground thawing actually started before the first InSAR acquisition of June 22, therefore, settlement may have occurred early in the season, particularly at site T1 where the soil is composed of saturated peat and fine sediments with visible ice lenses. Furthermore, highly variable local conditions around T1 may not have been reproduced by the averaging of the approximately 1.5 x 1.5 m ground pixel of the InSAR data. Although there is some discrepancy between the ground data and the InSAR results, the overall spatial distribution of seasonal surface displacement derived from the InSAR adequately reproduces the relative surface displacements between the major terrain units.

Figure 1. Thaw tube (T1) in wet and poorly drained marine sediments. See Nixon and Taylor (1994) for thaw tube description.

Figure 2. Thaw tube (T2) in dry and well drained glaciofluvial deposit. See Nixon and Taylor (1994) for thaw tube description.

CORRELATION WITH SURFICIAL GEOLOGY

InSAR results correlate very well with the surficial geology (Allard et al., 2011) showing stable ground or very low downward surface movement within the newer sectors of Iqaluit, which are built on bedrock and till. The greatest downward displacements were associated with the marine and glaciomarine deposits in the vicinity of the older part of the city, the west side of Frobisher Bay, in the surroundings of the airport, and in Apex. These displacements reflect seasonal settlement caused by thawing of the active layer (seasonally-frozen ground) or the permafrost (perennially-frozen ground). In marine and glaciomarine deposits ice lenses and ice wedge polygons were observed. Upward displacement may be due to ground heave, but could also be misrepresented horizontal movement if there is local surface slope. The InSAR results may vary from year to year without changing the good correlation with the surficial geology. A longer record of measurement will also aid to differentiate between seasonal and long-term trends in ground surface displacement.

DISCLAIMER

Recommended citation:
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Canadian Geoscience Maps
Cartes géoscientifiques du Canada

Canada

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InSAR data by N. Short, 2011

Geology by M. Allard, J. Doyon, and V. Mathon-Dufour, 2010

Surficial geology mapping based on ground surveys (2010–2011; M. Allard, V. Mathon-Dufour, J. Doyon, E. L'Hérault, and A-M. LeBlanc), and air photo interpretation by M. Allard, V. Mathon-Dufour, and J. Doyon using 1:20 000 scale black and white vertical photos, flight line A11535, July 23, 1948, photos 1–43.

Cartography by J. Doyon, V. Mathon-Dufour, and R. Boivin

Map projection Universal Transverse Mercator, zone 19.
North America Datum 1983

Seasonal ground displacement was derived for Iqaluit using interferometric synthetic aperture radar (InSAR) data from the summer of 2011. RADARSAT-2 Spotlight scenes on a descending orbit were acquired on June 22, July 16, August 09, September 02, and September 26. The data were interferometrically stacked and the three months of summer vertical displacement calculated according to the methodology outlined in Short et al. (2011). Each displacement measurement represents an area of approximately 1.5 x 1.5 m on the ground.

Infrastructure on this map provided by the city of Iqaluit, 2010.

SEASONAL SURFACE DISPLACEMENT DERIVED FROM INSAR
IQALUIT
Nunavut
1:15 000

250 0 250 500 750 1000 1250 1500 m

Shaded relief image prepared by J. Doyon and derived from digital elevation model created from 50 cm Worldview-1 stereo satellite images acquired August 19, 2008. 1 m DEM created with proprietary stereo image matching process by PhotoSat Information Ltd.
Illumination: azimuth 315°, altitude 45°, vertical factor 1x

Proximity of the North Magnetic Pole causes the magnetic compass to be erratic in this area.
Magnetic declination 2012, 29°58'W, decreasing 25.0' annually.

The Geological Survey of Canada welcomes corrections or additional information from users.

This publication, including digital data, can be downloaded free of charge from GeoPub (http://geopub.nrcan.gc.ca/). It is also available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/bookstore).

CANADIAN GEOSCIENCE MAP 66
(preliminary version)
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Cover and additional panels are 17cm wide when folded.