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Dynamics and Change of the Devon Ice Cap, Nunavut

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Dates in the field: 18 April – 14 May, 2012.
This research program aims to quantify the mass change rate of Canada's Arctic ice caps, determine the underlying causes and mechanisms of change, and evaluate the significance of these changes for global sea level. The program relies on remote sensing to achieve these goals, but fieldwork is essential to validate remote sensing measurements and understand the mechanisms of change. Fieldwork on the Devon Island Ice Cap has two major components: (i) calibration and validation of the radar altimeter on the CryoSat2 satellite (a collaboration with David Burgess of the Geological Survey of Canada), a new tool for monitoring changes in the thickness, volume, and mass of Arctic ice caps, and (ii) a study of ice dynamics, hydrology, and iceberg calving at the Belcher Glacier that is designed to explore how tidewater outlet glaciers respond to climate change and contribute to overall mass loss from Arctic ice caps.

Recent Progress

Changes in the mass balance of Canada's Arctic ice caps in the 21st century are unprecedented in the 54-year period of observations. Year-to-year changes in the mass balance of these glaciers are mainly due to changes in summer climate and surface melting. The decade of the 2000s had the warmest summer temperatures in the last 60 years, and 2005-2009 was the warmest 5-year period. Across the Queen Elizabeth Islands, measured mass loss rates after 2005 were up to 3.8 times higher than the ~50 year average. Modeling of the regional surface mass balance and estimates of mass change rates based on satellite laser altimetry and gravity measurements show that from 2007-2009, melting of ice caps in the Canadian Arctic was probably the single largest regional mass contributor to global sea level rise after the Greenland and Antarctic ice sheets. Our annual surveys of the Devon Ice Cap show that there has been a huge change since 2005 in how quickly snow is turned into glacier ice. Every year now, even at the highest elevations on the ice cap where, until the 2000s, surface melt occurred only once or twice a decade, surface meltwater is penetrating deeply into snow and firn near the glacier surface and refreezing to form ice. The last time this happened was around 4200 years ago.

2012 Field Season:

(i) ***CryoSat calibration-validation***. Changes in the amount of ice within snow and firn change how energy transmitted by the CryoSat2 radar altimeter is reflected from the ice cap. With more ice present, more energy is reflected from within the snow and firn relative to the amount reflected from the ice cap surface. This may reduce the accuracy of the surface height measurements made by the altimeter. To see if this is the case, we have made measurements of surface height and height change along the "CryoSat line" with GPS every year since 2004. We use ground-penetrating radar (GPR) and shallow ice cores to document the amount of ice in the snow and firn. These data allow us to check the accuracy of the surface height and height change measurements made by the satellite altimeter and assess how it is affected by changes in snow and firn properties across the ice cap and over time.

2012: GPS and GPR surveys were conducted along the 47 km long CryoSat line. We also conducted GPR surveys of four 100 m by 200 m grids and collected shallow ice cores along the CryoSat line to produce detailed three-dimensional maps of the structure of the upper 10 m of the ice cap. We retrieved ten 16 m deep cores [5 along the CryoSat line between ~1800 m.a.s.l. and 1400 m.a.s.l.], logged the distribution of ice layers and firn in each core using infrared photography and measured density profiles for each core. Comparison with results from the same locations in previous years allows us to document changes in the structure of the firn layer that have resulted from recent summer warming, and show how more rapid conversion of snow to ice is resulting in lowering of the ice cap surface. This is important because these changes in surface elevation do not indicate loss of mass from the ice cap. To test whether increased refreezing of meltwater within the firn has warmed the firn by release of latent heat, we also measured temperature profiles in 15m deep boreholes at several locations in the ice cap summit region, where temperatures had been measured in 1970 and 2004. These measurements show the firn has warmed by about 5.7ºC since 1970, and 3.8ºC since 2004, while the air temperature has increased by 1.8ºC since 1970 and 1ºC since 2004. Thus, between two thirds and three quarters of the firn warming is due to latent heat release from meltwater refreezing in the firn.

(ii) ***Belcher Glacier:*** We made a repeat GPS survey along a longitudinal profile that has been measured each year since 2007, to determine annual changes in the glacier's thickness and surface elevation. We maintained a series of continuously recording GPS sensors that measure the glacier's velocity throughout the year. Batteries were replaced, data from 2011/2012 were collected, and the GPS sensors were set up to record for another year. GPS sensors that were no longer functioning were removed and will be replaced in 2013. Several time-lapse cameras were installed along a system of interconnected supraglacial lakes and streams to document the processes involved in lake drainage events that appear to deliver water to the glacier bed and affect the rate of glacier flow. We also serviced and retrieved data from a weather station that provides us with information about when, and how rapidly, melting occurs on the glacier surface in summer.

Five high-resolution time-lapse cameras were installed to observe iceberg calving from the glacier. Ground control points [latitude, longitude, and elevation of identifiable features] were measured to facilitate analysis of these photographs. Two-component geophones, an audio recording system, and two sets of accelerometers were also installed in the terminus region. The data collected from these instruments will help us identify and characterize iceberg calving events and, when interpreted in conjunction with the velocity data obtained from the GPS sensors, will help us investigate the relationship between glacier velocity and iceberg calving.

NRI-ᑯᓐᓄᑦ ᐊᕐᕌᒍᑕᒫᖅᓯᐅᑎ ᐅᓂᒃᑳᖅ (ᓄᕕᐱᕆ 2012)
ᖃᐅᔨᓴᕈᓐᓇᐅᑎᖓᑕ ᓇᐃᓴᖓ 02 010 12R-M

ᖃᓄᐃᓕᖓᓂᖓ ᐊᓯᔾᔨᖅᐸᓪᓕᐊᓂᖓᓄ ᑕᓪᓗᕈᑎᒥ ᓯᕐᒥᐊᓘᑉ ᖄᖓᓂ, ᓄᓇᕗᒥ

ᒫᑎᓐ ᓵᑉ, ᓄᓇᓕᕆᔨᒃᑯᑦ ᓯᓚᓐᓂᐊᖅᐲᓪᓗ ᖃᐅᔨᓴᖅᑎᖏᑦ, ᐃᐊᓪᐹᑕᒥᐅᑦ ᓯᓚᕐᑐᒃᓴᕐᕕᔪᐊᖓᓂ

ᓄᓇᒨᓕᐅᖅᑐᑦ 2012-ᒥ: ᐲᑕ ᐱᓯ, ᐳᕌᑦ ᑖᓂᐊᓪᓴᓐ, ᒋᐱᕆᐊᓕ ᒌᔅᑳᓐ, ᑳᓛᓐ ᒧᐊᑎᒧ, ᐃᐊᓐ ᓯᑯᕋᐃᕗ (ᐃᐊᓪᐹᑕᐅᑉ ᓯᓚᕐᑐᒃᓴᕐᕕᔪᐊᖓᓂᑦ)
ᐅᓪᓗᐃᑦ ᓄᓇᒨᖅᓯᒪᓂᕆᓚᐅᖅᑕᖏᑦ: 18 ᐃᐳᓗ – 14 ᒪᐃ, 2012.
ᖁᕝᕙᖃᐅᔨᓴᕈᑕᐅᔪᓂ ᑐᑭᓯᓇᓯᐊᖅᑐᒍᑦ ᐊᒃᑐᐊᓂᖏᓐᓂᒃ ᓯᓚᐅᑉ ᐊᓯᔾᔨᖅᐸᓪᓕᐊᓂᖓᓄᑦ ᖃᓄᑎᒋ ᓱᒃᑲᓕᓴᕐᒪᖔᑕ ᑲᓇᑕᐅᑉ ᐅᑭᐅᖅᑕᖅᑐᖓᓂ ᓯᕐᒥᐊᓗᐃᑦ ᖄᖏᓐᓂ, ᐆᒃᑐᕋᐃᓇᓱᐊᕐᒪᑕ ᕿᕝᕙᓂᖏᓐᓂᒃ ᐊᓯᔾᔨᖅᐸᓪᓕᐊᓂᖏᓐᓂᓗ, ᐊᒻᒪᓗ ᖃᓄᑎᒋ ᑕᒪᒃᑯᐊ ᓱᕚᓪᓕᐅᑕᐅᖓᖔᑕ ᓯᓚᕐᔪᐊᒥ ᓄᓇᐃᑦ ᓱᕐᔫᖏᓐᓄᑦ. ᓯᓚᒧᑦ ᖁᖓᕝᕙᑕᐅᓯᒪᔪᓂᒃ ᐆᒃᑐᕋᐅᑎᖃᖅᓱᑕ ᐃᓕᐅᖅᑲᐃᓯᒪᔪᓂ ᓄᓇᒥ ᕿᕝᕙᔪᓂᒃ ᓱᓕᖕᒪᖔᑕ ᐊᐅᔾᔭᒃᑯᑦ ᑕᑯᔾᔭᖅᑐᓚᐅᖅᐸᒃᓱᒋᑦ ᓱᓕᒋᐊᖃᕐᒪᑕ ᓯᓚ ᐊᓯᔾᔨᖅᐸᓪᓕᐊᓂᖓᓄᑦ ᐆᒃᑐᕋᐅᑏᑦ. (i) ᐆᒃᑐᕋᓗᑎ ᓱᓕᓂᕋᕈᑎ ᓇᓚᐅᑎᒃᑯᑦ ᐆᒃᑐᕋᖅᑕᐅᓗᑎᒃ ᐳᖅᑐᓂᖏᑦ CryoSat2-ᒥ ᖁᖓᕝᕙᑕᐅᓯᒪᔪᒥ (ᐱᓕᕆᐊᕆᔭᐅᔪᖅ ᑖᓐᓇ ᐆᕕᑎ ᐳᒋᔅᒧᑦ ᑲᓇᑕᒥ ᐅᔭᕋᓐᓂᐊᖅᑎᒃᑯᓐᓄᑦ), ᓄᑖᖅ ᑖᓐᓇ ᓴᓇᖅᑯᑎ ᐊᓯᔾᔨᖅᐸᓪᓕᐊᓂᖏᓐᓂᒃ ᐆᒃᑐᕋᐅᑎ ᐃᔾᔪᓂᖓᓂᒃ, ᐊᒃᑎᒋᓂᖓᓂᒃ, ᐅᕐᑭᖕᖏᓐᓂᖓᓂᓗ ᓯᕐᒥᐊᓘᑉ ᑕᓪᓗᕈᑎᐅᑉ ᖄᖓᓂ, ᐊᒻᒪᓗ (ii) ᖃᐅᔨᓴᕆᐊᓪᓗᑎᒃ ᐱᖅᑯᓯᖓᓂᒃ, ᓯᑯᓯᒪᔪᑦ ᐃᒪᓐᓂᐊᖅᑕᐅᓪᓗᓂ, ᐱᕐᑲᓗᔭᐃᔭᖅᐸᓪᓕᐊᓂᖓᓗ ᑕᒪᐃᓐᓂᒃ ᓯᓚ ᒪᓕᒃᓯᒍ ᓲᕈᔪᒃᐸᓪᓕᐊᓂᖓᓂ ᐆᒃᑐᕋᖅᑕᐅᓪᓗᓂ ᓯᕐᒥᐊᓗᒃ.
ᒫᓐᓇ ᐱᕚᓪᓕᐊᓂᕆᔭᐅᔪᑦ:
ᐊᓯᔾᔨᖅᐸᓪᓕᐊᖕᒪᑕ ᑲᓇᑕᐅ ᐅᑭᐅᖅᑕᖅᑐᖓᓂ ᓯᕐᒥᐊᓗᐃᑦ ᑕᐃᓱᒪᖓᓂᓂᑦ ᐅᑭᐅᓂ 100-ᓂ ᐱᓗᐊᖑᐊᓕᖅᓱᑎᒃ ᑕᒪᑐᒪᓂ 54-ᓂ ᐅᑭᐅᖑᕋᑖᖅᑐᓂ ᖃᐅᔨᓴᖅᑕᐅᓕᖅᑎᓪᓗᒋ. ᐊᕐᕌᒍᑕᒫᑦ ᖃᓄᐃᓕᖅᐹᓪᓕᖅᑲᑦᑕᕐᓂᖏᑦ ᓯᓚᒥᒃ ᒪᓕᒃᓯᑎᒃ ᐊᐅᔭᒃᑯᑦ ᖄᖏᑦ ᐊᐅᖅᑲᑦᑕᕐᒪᑕ. ᐅᑭᐅᖑᕋᑖᖅᑐᓂ ᕐᑯᓕᓂ ᑕᒪᑐᒪᓂ 2000 ᐱᒋᐊᖅᑎᓪᓗᒍ ᐅᖅᑰᖑᓂᖅᐹᖑᓕᐅᕐᒪᑦ 60-ᓂ ᐅᑭᐅᓂ, ᐊᒻᒪᓗ 2005-2009 ᐅᖅᑰᖑᓂᖅᐹᖑᓪᓗᓂ ᑕᓪᓕᒪᓂ ᐅᑭᐅᓂ. ᖃᐅᔨᐃᕐᑐᓕᒫᒥ ᑯᐃ ᕿᑭᖅᑕᕐᑯᑎᖏᓐᓂ, ᐆᒃᑐᕋᖅᑕᐅᓯᒪᓕᖅᑐᑦ ᐱᕐᑲᓗᔭᖅᐸᓪᓕᐊᓂᖏᑦ 2005-ᒥ 3.8-ᒥ ᕐᑯᑎᖕᓂᕐᑲᓚᐅᕐᒪᑦ ᑕᒪᑐᒪᓂ 50-ᓂ ᐅᑭᐅᓂ. ᐆᒃᑐᕋᖅᑕᐅᓂᖓ ᐊᒃᑎᒋᓂᖓᑕ ᐊᒥᐊᒃᑯᖓ ᓱᒃᑲᓂᖅᓴᐅᓕᖅᑎᓪᓗᒋᑦ ᐊᐅᒃᐸᓪᓕᐊᔪᑦ ᖁᖓᕝᕙᑕᐅᓯᒪᔪᒃᑯᑦ ᑕᑯᒃᓴᐅᖕᒪᑕ ᐃᔾᔪᓂᖏᓪᓗ ᐆᒃᑐᕋᖅᑕᐅᓯᒪᓕᕐᒪᑕ 2007-2009, ᐊᐅᑉᐸᓪᓕᐊᓂᖏᑦ ᓯᕐᒥᐊᓗᐃᑦ ᑲᓇᑕᐅᑉ ᐅᑭᐅᖅᑕᖅᑐᖓᓂ ᐊᑕᐅᓯᖅ ᐊᖏᓂᖅᐹᖑᓪᓗᓂ ᐃᒃᐱᖕᓇᕐᓂᖅᐹᖑᓕᐅᖅᑐᖅ ᓄᓇᕐᔪᐊᒥ ᓱᕙᐃᑦ ᐅᓕᑦᑕᕐᓂᖏᓐᓄᑦ ᑭᖑᓂᖓᓂ ᑲᓛᓪᓕᒥᐅᑦ ᓄᓇᖓᑕ ᖄᖓᓂ ᓯᕐᒥᐊᓗᖓᓂᑦ ᐊᒻᒪᓗ ᓄᓇᕐᔪᐊᑉ ᐊᑖᓂᒥᐅᑦ

ᓯᕐᒥᐊᓗᖓᓂᑦ. ᐊᕐᕌᒍᑕᒫᑦ ᐆᒃᑐᕋᖅᑕᐅᕐᑲᑦᑕᖅᓱᓂ ᑕᐃᒪᓐᓇ ᑖᓪᓗᕈᑎᐅᑉ ᓯᕐᒥᐊᓗᐊ ᐊᒃᓱᑲᓪᓚᒃ ᐊᓱᐃᓪᓕᖅᐸᓪᓕᐊᖓᒪᑦ ᑕᐃᒪᖓᓂᑦ 2005-ᒥᑦ ᐆᒃᑐᕋᖅᑕᐅᓯᒪᖕᒪᑕ ᖃᓄᑎᒋ ᓱᒃᑲᓕᑎᒋᔪᒥᒃ ᐊᐳᑎ ᖄᖓᓅᑦᑐᖅ ᓯᕐᒥᖑᓱᖑᖕᒪᖔᑦ. ᐊᕐᕌᒍᑕᒫᑦ, ᖄᖓᓂᓘᓐᓅᑦ, 2000-ᓂ ᐊᐅᒃᐸᓚᐅᖏᒻᒪᑦ ᐃᒻᒪᖄ ᐅᑭᐅᑦ ᖁᓖᑦ ᓈᓐᖓᑕ ᐊᐅᕚᕐᔪᒃᐸᔪᔪᖅ, ᒪᓐᓇ ᐊᐳᑎ ᖄᖓᓂ ᐊᐅᒃᑳᖓᑦ ᐃᓗᐊᓄᑦ ᑰᓕᖅᑲᑦᑕᕐᒪᑦ ᑕᐃᒪ ᓯᕐᒥᖑᓂᐊᕐᓗᓂ. ᑭᖑᓪᓕᖅᐹᒥ ᑕᐃᒪᐃᓚᐅᖅᓯᒪᔪᖅ 4200 ᐅᑭᐅᖑᓚᐅᖅᑐᓂ.

<u>2012-ᒥ ᓄᓇᒨᖅᓯᒪᑎᓪᓗᒋᑦ:</u>

(i) *CryoSat-ᑯᑦ ᐆᒃᑐᕋᖅᑕᐅᔪᑦ-ᓱᓕᓂᕋᖅᑕᐅᔪᓪᓗ*. ᓯᕐᒥᖑᖅᐸᓪᓕᐊᓂᖏᑦ ᐊᐳᑎ ᖄᖓᓂ ᐆᒃᑐᕋᖅᑕᐅᓚᐅᕐᒪᑕ ᖁᕝᕙᑕᐅᓯᒪᔪᒃᑯᑦ CryoSat2 ᓈᓚᐅᑎᖓᒍᑦ ᐳᖅᑐᓂᖓ ᖄᖓᓂ. ᓯᖅᑲᕝᕙᓂᖓ ᐆᒃᑐᕋᖅᑕᐅᔪᓐᓇᕐᒪᑦ ᖁᓖᓂᑦ ᐊᐱᖔᖓᑦ ᒪᓂᕋᖓ ᐳᖅᑐᓕᖅᐹᓪᓕᕐᑲᑦᑕᕐᓂᖓ. ᓱᓕᒐᓗᐊᕐᒪᖔᑦ ᑕᑯᔭᒃᑐᖅᑕᐅᓪᓗᓂ ᐆᒃᑐᕋᖅᑕᐅᓚᐅᖅᑐᖅ ᐳᖅᑐᓂᖓᓄᑦ ᐊᓱᐃᓗᕈᑕᐅᔪᑦ ᓯᕐᒥᐊᓘᑉ ᖄᖓᓂ ᐆᒃᑐᕋᐅᑎᓂᒃ ᐃᓕᐅᖅᑲᐃᕕᐅᓪᓗᓂ ᑐᑭᓕᐊᖅᑐᒥᒃ ᑕᐃᔭᐅᔪᒥᒃ "CryoSat line" ᐊᑐᖅᓱᑎᒃ GPS-ᓂᒃ 2004-ᒥ. ᐃᑎᓂᖓᓂᓗ ᓈᓚᐅᑎᓂᒃ ᐊᑐᖅᓱᑎᒃ ᐆᒃᑐᕋᐅᑎᖅᑲᖅᑐᑦ ᑕᐅᓇᓂ ᖃᓂᓐᓂᖅᓴᒥ ᓯᕐᒥ ᖃᓄᑎᒋ ᐊᐱᖅᑲᑦᑕᕐᒪᖔᑦ ᓯᖅᑲᕝᕙᓂᖓᓗ. ᑕᒪᒃᑯᐊ ᐆᒃᑐᕋᐅᑏᑦ ᐊᑐᖅᑲᑦᑕᖅᑕᖃᑦ ᓱᓕᒐᓗᐊᕐᒪᖔᖏᓐᓂᒃ ᐊᖏᕈᐊᓪᓚᒃᑲᓂᓱᕆᑦ ᐳᖅᑐᓂᖓ ᐊᓱᐃᓪᓕᖅᐸᓪᓕᐊᓂᖓᓂᓗ ᖁᕝᕙᑕᐅᓯᒪᔪᒃᑯᑦ ᐆᒃᑐᕋᖅᑕᐅᔪᕕᓃᑦ ᑕᐃᓱᒪᖓᓂᓂ ᑲᑎᖅᓱᖅᑕᐅᓂᐊᖅᑐᑦ ᓱᕚᓪᓕᕐᒪᖔᑕ ᑐᑭᓯᔭᐅᓇᓱᐊᖅᓱᑎᒃ ᒫᓐᓇᒧᑦ.

<u>2012-ᒥ:</u> GPS-ᑯᑦ ᐊᒻᒪᓗ GPR-ᑯᑦ ᑕᒪᓐᓇ ᓯᕐᒥᒃᑯᑦ 47 ᑭᓵᒥᑐᒥᒃ ᑕᑭᓂᖅᑲᖅᑐᖅ ᑖᓐᓇ CryoSat line. ᐆᒃᑐᕋᕐᑲᑦᑕᓚᐅᕐᒥᔪᑦ GPR-ᑯᑦ 100-200-ᒦᑐ ᓱᒃᑭᑕᒥ ᐃᓗᐊᓂ ᑲᑎᖅᓱᐃᓪᓗᑎᒃ ᓯᑯᓂ ᐊᐳᑎᓂᓗ ᑕᒪᖓᑦ ᖁᕝᕙᑕᐅᓯᒪᔪᒃᑯᑦ ᐆᒃᑐᕋᖅᑕᐅᓯᒪᔪᒥ ᓄᓇᖑᐊᒃᑯᑦ ᑕᑯᒃᓴᐅᓚᑦᑖᖅᑐᒥᒃ ᓴᓇᓪᓗᑎᒃ ᑕᒪᑐᒪ ᓄᓇᐅᑉ ᐋᕐᑭᒃᓱᖅᓯᒪᓂᖓᓂ ᓄᓇᖑᐊᓕᐅᓚᐅᖅᑐᑦ 10-ᒦᑐᒥᒃ ᐃᑎᓂᖅᑲᖅᑐᒥᒃ ᖁᓖᓂᑦ. ᐱᓚᐅᕈᓪᓗᑎᒃ 16-ᒦᑐᒥᒃ ᐃᑎᓂᖅᑲᖅᑐᒥᑦ ᓯᑯᒥᒃ [5-ᓂᒃ CryoSat line-ᒥᑦ ᐊᑯᓐᓂᐊᓂᑦ ~1800 m.a.s.l. ᐊᒻᒪᓗ 1400 m.a.s.l.], ᑎᑎᕋᖅᑕᕝᕙᓪᓗᑎᒃ ᐳᖅᑐᓂᖏᑦ ᓇᒦᕆᐊᖏᓪᓗ ᓯᕐᒦᑦ ᐊᑖᓂ ᑖᖅᑐᖅᓱᐅᑎᓗᑦ ᐊᔾᔨᓕᐅᖅᓱᕆᑦ ᐃᓗᓕᖏᑦ ᐊᑐᓂ ᓯᕐᒦᑦ ᐱᔭᐅᔪᑦ. ᐃᒡᓗᐊᓄᖔᖅ ᖁᓚᕝᕙᓂᖏᑦ ᐊᕐᕌᒎᓚᐅᖅᑐᓂ ᑕᒫᖓᓴᐃᓐᓇᖅ ᐆᒃᑐᕋᖅᑕᐅᔪᕕᓃᑦ ᓯᖅᑲᕝᕙᓂᖓᓂᒃ ᐊᕐᕌᓂ ᐊᐅᔭᐅᓚᐅᖅᑐᒥ ᐅᖅᑰᓯᕚᓪᓕᕐᓂᖓᓄᑦ. ᑕᒪᓐᓇ ᐱᒻᒪᕆᐅᖓᑦ ᐆᒃᑐᕋᖅᑕᐅᒋᐊᖅᑲᕐᒪᑦ ᖄᖓᓂ ᓯᖅᑲᕝᕙᓂᖓ ᐊᓯᑕᕝᕙᖏᒻᒪᓪᓕ. ᖃᓄᑎᒋ ᖁᐊᖅᐸᓪᓕᐊᓂᖓ ᐊᐅᔭᒃᑯᑦ ᐊᐅᒃᓯᒪᕐᑲᑦᑕᖅᑐᑦ ᖄᖓᓂ ᕿᒥᕈᔭᐅᓪᓗᑎᒃ ᐊᐅᒃᐸᓪᓕᐊᓂᖏᓪᓗ ᖃᓄᑎᒋ ᐅᖅᑰᓯᖅᑲᑦᑕᕐᒪᖔᑕ ᐊᒻᒪᓗ ᐃᑰᑕᕕᐅᓪᓗᓂ 15-ᒥᑐᒥᒃ ᐃᑎᓂᓕᖓᓂᒃ ᐊᔾᔨᕉᖏᑦᑐᓂ ᑕᒫᓂ ᖄᖓᓂ, ᓯᓚᖓᓂᐊᖅᑕᐅᓯᒪᓕᖅᑐᒥ 1970-ᓂᑦ ᐅᑭᐅᖅ 2004-ᒧᑦ. ᐆᒃᑐᕋᐅᑎᒃᑯᑦ ᓇᓗᓇᐃᖅᑕᐅᓯᒪᓕᖅᑐᖅ ᐅᖅᑰᓯᕝᕙᓂᖏᑦ 5.7°C 1970-ᓂ, ᐊᒻᒪᓗ 3.8°C-ᒧᑦ 2004-ᒥ. ᑕᐃᒪᓐᓇ ᕚᕝᕕᒪᖄ 2/3-ᒥᑦ ᐅᕝᕙᐊᖅ 3/4-ᒧᑦ ᐅᖅᑰᓯᕝᕙᖓᑦ ᓯᕐᒥᐊᓗᒃ ᖃᖓᓂ ᐊᐅᑉᐊᓪᓕᐊᓂᖅᑲᖅᑐᖅ ᑕᐃᒪᖓᓂᑦ ᐅᐱᖔᒃᑯᑦ ᐊᐅᒃᐸᓪᓕᐊᔪᓄᑦ ᑯᕕᐅᓪᓗᓂ ᑕᒪᓐᓇ.

(ii) *ᐱᐊᓪᓱ ᓯᕐᒥᐊᓗᐊᓂ:* ᐅᑎᒃᑲᓐᓂᓚᐅᕋᑦᑕ GPS-ᑯᑦ ᑕᒪᓐᓇ ᐆᒃᑐᕋᖅᑐᒃᑲᓐᓂᖅᓱᓂ ᑐᑭᓕᐊᖅᑐᒥᒃ ᑕᐃᒪᓐᓇ ᐊᕌᒍᑕᒪᑦ ᐆᒃᑐᕋᖅᑕᐅᕐᑲᑦᑕᓕᖅᑐᖅ

2007-ᒥᓂᑦ, ᖃᐅᔨᓇᓱᐊᖅᓱᑎᒃ ᖃᓄᑎᒋ ᐊᖅᑮᒍᑕᓛᑦ ᐊᓯᔾᔨᖅᑕᕐᓂᖓᓂᒃ ᓯᕐᒥᐊᓘᑉ ᐃᑎᓂᖓ ᒪᓂᕋᖓᓗ. ᑕᐃᒪᖓᑦ ᐆᒃᑐᕋᖅᑕᐅᖏᓐᓇᖅᑐᑦ ᑖᕗᖓ ᐃᓕᔭᐅᓯᒪᔪᓄᑦ ᓂᐱᓕᐅᖅᑕᕝᕙᓪᓗᑎᒃ GPS-ᑯᑦ ᑕᐅᓄᖓ ᑰᒃᐸᓪᓕᐊᓂᖏᑦ ᓯᕐᒥᐊᓗᐃᑦ. ᐹᑐᓇᖏᓪᓗ ᐊᓯᔾᔨᖅᑕᐅᒋᐊᖅᑐᖃᑦᑕᖅᓱᑎᒃ ᐊᖅᑮᒍᑕᓛᑦ. GPS ᐃᓚᖏᑦ ᐊᔪᓕᖅᓯᒪᔪᑦ ᐃᓇᖏᖅᑕᐅᓂᐊᖅᑐᑦ ᐅᑎᕈᑦᑕ 2013-ᒥ. ᐊᒥᓱᑦᑕᐅᖅ ᐊᔾᔨᓕᐅᕈᑏᑦ ᐃᓕᐅᖃᖅᑕᐅᓚᐅᕐᒥᔪᑦ ᐅᐊᒍᓕᓈᒃᑐᓂ ᑕᓱᕐᓂ ᓯᕐᒥᐅᑉ ᖄᖓᓂ ᑰᖓᓖᓂᓗ ᓇᒧᑦ ᑰᒃᐸᓪᓕᐊᓂᖏᑦ ᑎᑎᕋᖅᑕᐅᓂᐊᕐᒪᑕ ᑕᒫᒃᑯᐊ ᓯᕐᒥᐊᓘᑉ ᐃᓗᐊᒍᑦ ᑰᕐᑲᑦᑕᖅᑐᑦ ᐊᒻᒪᓗ ᓱᓚᓐᓂᐊᕈᑎᓂᒃ ᐃᓕᐅᖅᑲᖅᑕᐅᓯᒪᔪᓂᒃ ᑲᑎᖅᓱᐃᒋᐊᖅᑐᖅᓱᑎᒃ ᖃᖓ, ᐊᒻᒪᓗ ᖃᓄᑎᒋ, ᐊᐅᒃᐸᓪᓕᐊᓂᖓᓂᒃ ᐆᒃᑐᕋᐅᑕᐅᒋᓪᓗᑎᒃ ᐊᐅᔭᒃᑯᑦ.

ᑕᓪᓕᒪᓂᒃ ᑕᑯᒃᓴᐅᑦᑎᐊᕈᓐᓇᖅᑐᓂᒃ ᐊᔾᔨᓕᐅᕈᑎᓂᒃ ᐃᓕᐅᖅᑲᐃᓚᐅᖅᑐᑦ ᑕᑯᓂᐊᕐᒥᖕᒪᑕ ᐱᖃᓗᔭᓂᒃ ᑲᑕᒃᐸᓪᓕᐊᔪᓂᒃ ᓯᕐᒥᒥᑦ. ᓄᓇᒥᑦ ᐊᐅᓚᑕᐅᕙᖅᑲᖅᓱᑎᒃ [ᓄᓇᖑᐊᑎᒍᑦ ᓇᒦᒋᐊᖕᒋᑕ ᓈᓴᐅᑎᖕᒋᓐᓂᒃ ᐊᑐᖅᓱᑎᒃ, ᐳᖅᑐᓂᖕᒋᓪᓗ, ᖃᓄᐃᓐᓂᖕᒋᓪᓗ] ᐆᒃᑐᕋᖅᑕᐅᓪᓗᑎᒃ ᐊᔾᔨᖑᐊᖕᒐᓂ. ᒪᕐᐹᖕᓂᒃᑕᐅᖅ ᓂᐱᓕᐅᕈᑎᓂᒃ ᐃᓕᓯᓚᐅᕐᒥᔪᑦ ᐃᓖᓐᓂᒃᑯᑦ ᓂᐱᓕᐅᓇᕐᑲᑦᑕᕐᓂᐊᖅᑐᓂᒃ, ᒪᕐᐹᖕᓂᓗ ᐃᖕᒋᕋᓂᖕᒐᓂᒃ ᐆᒃᑐᕋᐅᑎᓂᒃ ᐃᓕᓯᓪᓗᑎᒃ ᐹᖕᒐᓂ. ᓂᐱᓕᐅᖅᓯᒪᔪᓂᑦ ᖃᐅᔨᔪᓐᓇᕐᓂᐊᕋᑦᑕ ᖃᓄᑎᒋ ᐊᑯᓚᐃᓐᓂᕐᑲᕐᒪᖔᑕ ᐱᖃᓗᔭᐃᖅᑲᑦᑕᕐᓂᖏᑦ, ᐃᓚᓕᐅᑎᓗᒋᑦ ᓱᒃᑲᓕᓂᖓ GPS-ᑯᑦ ᑕᑯᓗᒋᑦ, ᖃᐅᔨᔪᑕᐅᓂᐊᕐᒪᑕ ᖃᓄᑎᒋ ᓱᒃᑲᓕᓴᕐᓂᕐᑲᖅᓱᑎᒃ ᖃᓄᑎᒋ ᐱᖃᓗᔭᐃᔭᕋᔪᖕᒪᖔᑕ.