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LOWER CHURCHILL PROJECT

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2014-2015 Ice Observation Survey
Mud Lake Crossing, Lower Churchill River
LC-EV-107

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EXECUTIVE SUMMARY

The Ice Survey Program for the Lower Churchill Project (LCP) includes surveying ice freeze-up and break-up in the Lower Churchill River pre- and post-impoundment. The program during the 2014-2015 ice season is a continuation of previous monitoring and was to confirm baseline conditions and collect additional data to better understand the ice conditions in areas potentially influenced by the LCP. The survey program included the following objectives and activities:

- Review of web camera images at Mud Lake for planning purposes;
- Communications with Mud Lake residents to document freeze-up and break-up processes;
- Photographic surveys by helicopter during freeze-up and break-up periods of the Lower Churchill River between Lake Melville and Muskrat Falls;
- Estimation of ice floe concentration;
- Collection of ice thickness measurements along the ice bridge crossing route at Mud Lake;
- Acquisition and interpretation of radar satellite imagery to monitor the freeze-up and break-up processes; and
- Estimation of ice floe velocity using the updated hydraulic model (HEC-RAS) of the Churchill River.

Photographs of the Lower Churchill River were collected by aerial observation from a helicopter during the ice freeze-up period (November 22 to 25, 2014; 850 photographs) and ice break-up period (May 17 to 19, 2015; 530 photographs) from Lake Melville up river to Muskrat Falls. Photographic documentation involved travelling along the southern bank of the river to collect side view photographs while on the return trip, photographs were taken looking downstream on the river, from bank to bank.

A web camera at the Mud Lake crossing on the north side of the Lower Churchill River transmitted images by satellite and were uploaded as near real time data to the Government of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Management Division (NLDEC/WRMD) web site. Daily review of images from this web camera was used to assist in planning helicopter surveys (above). Images during the period from November 17 to 28, 2014, and May 5 to 22, 2015, were used to further document and describe the freeze-up and break-up conditions.

An ice floe concentration analysis was performed on 40 aerial photographs (18 for freeze-up and 22 for break-up) taken during the helicopter ice surveys, for the purpose of studying ice concentrations in the reach between Muskrat Falls and Mud Lake. The results included a processed image with ice cover and open water classes, with their respective area of coverage. During freeze-up, the percent of ice cover increased from November 22 to 23, 2014, from (mean ± Std. Dev.) 51.3 ± 25.1% ice cover to 57.3 ± 29.0% ice cover. The proportion of ice cover decreased on November 25 (47.9 ± 41.1%), largely due to declining ice cover (3.4%) at location #6, just above Muskrat Falls. During break-up, the percent of ice cover decreased from May 17 to 19, 2015 ranging from (mean ± Std. Dev.) 73.2 ± 33.7% to 42.4 ± 38.5. The proportion of ice cover was consistently lowest at location #6, just above Muskrat Falls.

The timing of the freeze-up and break-up processes during the 2014-2015 ice season were documented and compared with the long-term data record and the last ten years of observations. The date of freeze-up, as indicated by the day of the first snowmobile crossing, was November 24, 2014. The date of break-up, as indicated by the date of the first boat crossing, was May 18, 2015. The date of freeze-up was four days earlier than the long-term average (November 28) and 13 days earlier than the average for the last ten years (December 7). Similarly, the date of break-up was four days later than the long-term average (May 14) and nine days later than the average for the last ten years (May 9). The early freeze-up date in 2014 and late break-up date in 2015 resulted in a total ice covered period of 176 days for the 2014-2015 ice season.

Ice thickness measurements were completed between February 9 and 10, 2015, and a total of ten locations were augured along the ice crossing route at Mud Lake. The ice thickness was variable, averaging 82.6 centimetres (cm) ± 10.7 (Std. Dev.), ranging from 65 to 100 cm, and was solid throughout. Snow cover was considerable, ranging from 20 to 118 cm. The consistent thickness and solid ice conditions in 2015 were attributed to the extreme cold conditions and good snow cover.

Satellite images of the Lower Churchill River near Mud Lake were acquired and interpreted by C-CORE during the 2014-2015 ice season. Satellite Synthetic Aperture Radar (SAR) images were acquired by the Cosmo-Skymed (CSK) satellite constellation. Monitoring of SAR images was completed between November 23, 2014, and May 23, 2015, at a frequency of approximately every four days over the section between Muskrat Falls and Mud Lake. Daily SAR images were obtained during ice freeze-up from November 25 to 29, 2014, and break-up from May 7 to 20, 2015. A total of 60 SAR images were acquired and processed. Forty-six images had a spatial resolution of 30 metres (m) and were used to monitor the section of river between Muskrat Falls and Mud Lake. Fourteen high-resolution SAR images, with spatial resolution of 5 m, were used to monitor freeze-up and break-up of the ice cover at the Mud Lake crossing. C-CORE produced three products from the analyses of SAR images. The Ice Cover product identified areas in the image that were dark, indicating smooth ice cover or open water which helped elucidate the ice front. The Ice Classification product interpreted three ice classes: (i) open water or water on ice; (ii) non-consolidated or smooth ice surface; and (iii) consolidated or rough ice surface. The Change Detection product compared two images to determine whether there had been an increase, decrease, or no change in ice cover. The products from interpretation of the 60 SAR images are documented in this report.

Satellite monitoring of the Lower Churchill River began on November 23, 2014, focusing on freeze-up in the Mud Lake area and using high and medium resolution images up to December 3, 2014. Freeze-up occurred two weeks earlier than in 2013. The image acquired on November 23, 2014, showed suspended ice between Muskrat Falls and Happy Valley-Goose Bay. Downstream of Happy Valley-Goose Bay, the ice was consolidated due to the ice cover in Lake Melville. The SAR image products showed the accumulation continuing until the ice cover became stable and consolidated on December 3. The change detection results showed specific areas of ice accumulation and the spatial extent of ice coverage.

The first high resolution image for break-up monitoring was acquired on May 7, 2015, and a total of ten images were acquired to monitor the Mud Lake area during break-up. Open water first appeared in the river originating from Mud Lake and along the north side of the Churchill River, just east of Happy Valley-Goose Bay, on May 10. Ice cover conditions remained the same until May 14, 2015, where new leads developed and existing leads widened. The ice cover rapidly deteriorated beginning May 16, 2015. Most of the river was ice free, with the exception of the section just below Muskrat Falls, by May 23. The ice below Muskrat Falls was extremely thick and this is typically the last area in the lower reach of the Churchill River to become ice free.

The formation of the ice bridge at Mud Lake is dependent on the volumetric flow rate of ice arriving at the bridging location. Estimates of the volumetric flow rate of ice were made through observation of three variables: (i) ice floe concentration; (ii) ice floe thickness; and (iii) ice floe velocity. Volumetric flow rate of ice estimates were determined for four locations in the river: (i) upstream of Muskrat Falls; (ii) downstream of Muskrat Falls; (iii) near Blackrock Bridge; and (iv) near the Mud Lake crossing. Volumetric flow rate of ice was calculated to range from 8.2 (Near Blackrock Bridge) to 61.2 (Upstream of Muskrat Falls) $m^3 \cdot s^{-1}$.

1.0 INTRODUCTION

Mud Lake residents are dependent on a stable ice cover across the lower Churchill River for transportation to and from Happy Valley-Goose Bay and there are from 80 to 140 snowmobile crossings per week by Mud Lake residents during the winter season. Consequently, the environmental assessment of the Lower Churchill Project (LCP) paid particular attention to the possible effects of the proposed LCP on the ice dynamics in the reach below Muskrat Falls (Nalcor 2009). It was determined that hydraulic conditions downstream of Muskrat Falls were not expected to change as a result of the LCP and it was predicted that there would be no effect on river crossings during the ice-free parts of the year. It was predicted, however, that downstream of Muskrat Falls, in the area of Mud Lake, the freeze-up date would be delayed by two weeks and the break-up date would occur one week later than historical records (Hatch 2007; Nalcor 2009). This would affect river crossing by Mud Lake residents, as boats would be used to cross the river for two weeks longer in the fall and snowmobiles would be used one week longer in the spring.

In addition to the predicted effect on timing of freeze-up and break-up, predictions were made regarding the transition period during the freeze-up and break-up processes, that the ice cover may not be stable enough for crossing by snowmobile (freeze-up) or until the river is ice-free in the spring (break-up) allowing crossings by boat. These transition periods occur each year and during this time travel by boat or snowmobile is not possible. Ice modeling predictions made in the environmental assessment did not forecast a longer transition period; therefore, crossing of the river is not expected to be affected by the LCP, other than the change in timing.

Under pre-LCP conditions, ice bridging occurs at approximate chainage 0.2 km above Lake Melville and the ice cover progresses upstream from that point. Under post-LCP conditions, the volume of ice will be reduced by the Muskrat Falls Dam which will act as a physical barrier to ice transport from upstream to downstream reaches. A hydraulic analysis was completed to assess the potential for the ice bridge to form under post-LCP conditions and this analysis suggested that the volume of ice generated downstream of Muskrat Falls was sufficient for the formation of an ice bridge (Hatch 2010; Pryse-Phillips 2010). The strength (stability and thickness) of the ice forming the ice bridge was predicted to remain unaffected during the operation of the LCP.

Nalcor Energy (Nalcor) has been observing ice processes in the lower Churchill River since 2006 as part of the assessment of the LCP (Hatch 2007: SNC-Lavalin 2012a and b). Historical surveys were also conducted in the 1980s and 1990s by various parties (as reviewed in SNC-

Lavalin 2012b). Ice management is an important aspect of construction and operation of the Muskrat Falls hydroelectric plant and these studies have been conducted to better understand the ice conditions in the areas to be influenced by the LCP to better predict what could occur during construction and operation of the LCP. The LCP has committed to surveying ice formation in the lower Churchill River during pre- (baseline and LCP construction) and post-impoundment (operations) conditions. These predictions would allow Nalcor to take appropriate precautions and develop mitigation measures to manage potential problems due to ice. Nalcor has contracted Golder Associates Ltd. (Golder), who sub-contracted Sikumiut Environmental Management Ltd. (SEM) to develop and implement an ice surveying program to be completed during LCP construction to confirm baseline conditions and to expand the knowledge base on the timing of freeze-up and break-up in relation to the Mud Lake crossing location. This report presents the results of studies completed in the 2014-2015 ice season (year 2 of 3) during the initial construction phase of the LCP.

2.0 MATERIALS AND METHODS

2.1 Objectives

Nalcor has committed to surveying ice formation in the lower Churchill River pre- and post-impoundment. The objective of the program during the 2014-2015 ice season was to implement an ice surveying field program to be completed during the second year of the LCP construction to confirm baseline conditions. The survey program included the following objectives and activities:

- Daily review of images from the Government of Newfoundland and Labrador, Department of Environment and Conservation, Water Resources Management Division (NLDEC/WRMD) web camera at Mud Lake for the purpose of planning helicopter surveys.
- Communications with Mud Lake residents to support planning of helicopter surveys during the freeze-up and break-up processes.
- Photographic surveys by helicopter (daily) during the critical ice formation process at Mud Lake and the subsequent strengthening of the ice cover. Observations spanned the reach between Mud Lake and Muskrat Falls to observe the progression of the ice front.
- Photographic surveys by helicopter (daily) during the spring break-up process at Mud Lake, between Mud Lake and Muskrat Falls.
- Estimation of ice floe concentration via analysis of photographs taken during helicopter surveys at selected locations.
- Acquisition and interpretation of radar satellite imagery to determine ice formation at Mud Lake and to monitor the break-up process, as well as to monitor ice conditions during the period of intact ice.
- Estimation of ice floe velocity using the updated hydraulic model (HEC-RAS, USACE 2010) of the lower Churchill River at four locations:
    - Upstream of Muskrat Falls;
    - Downstream of Muskrat Falls;
    - Downstream of Blackrock Bridge; and
    - Near the Mud Lake ice bridge crossing.
- Collection of ice thickness measurements along the Mud Lake ice bridge crossing

2.2 Study Team

The study team members for this work and their area of responsibility are listed in Table 2.1. The overall project coordination and management was completed by SEM, in communication with Golder. SEM also completed the aerial observation surveys during the freeze-up (November 2014) and break-up (May 2015) periods and conducted the ice coring survey along the Mud Lake ice bridge crossing (February 2015). SEM also completed the project report with support and input from other team members.

The Centre for Cold Ocean Resource Engineering (C-CORE) acquired and analyzed Satellite Synthetic Aperture Radar (SAR) images from the Cosmo-Skymed (CSK) satellite constellation to monitor ice conditions on the lower Churchill River for the 2014-2015 ice season. Images were analyzed to identify ice types and delineate areas of open water during freeze-up and break-up of the ice cover in the Mud Lake area. C-CORE also completed an ice floe concentration analysis on 40 aerial photographs taken during the helicopter ice surveys.

Hatch Ltd. (Hatch) provided hydraulic analysis using a river model of the Lower Churchill River to determine the volumetric flow rate of ice arriving at the bridging location at Mud Lake. This included: (i) estimation of ice floe concentration via analysis of photographs taken during helicopter surveys (as provided by C-CORE); (ii) completing theoretical estimates of ice floe thickness (Stefan's Equation); and (iii) modelling estimates of ice floe velocity using the most up-to-date (2010) HEC-RAS model of the Lower Churchill River.

Table 2.1 Team Members for the 2014-2015 Ice Observations Surveys.

Team Member	Roles and Responsibility
SEM	
Dave Scruton, MES, Senior Scientist	Project Manager, coordination, client liaison, project report
Leroy Metcalfe, B. Sc, President	Financial control, project report QA/QC
Patrick Hamlyn, B. Eng., Engineer in Training	Field team lead, freeze-up survey
Robyn Bradley, B. Tech., Dipl. Mar. Env. Tech., Environmental Technician	Field team member, freeze-up survey and break-up survey
Stefan Cahill, Dipl. Geomatics, Director of Geomatics	Field team lead, ice thickness survey

Table 2.1 Team Members for the 2014-2015 Ice Observations Surveys. (Cont'd)

Team Member	Roles and Responsibility
SEM	
Brad Vaters, Fish Wild. Tech. Dipl., Environmental Technician	Field team member, ice thickness survey
Claire Moore-Gibbons, MES, Biologist	Field team lead, break-up survey
Jordan Hope, Mud Lake Resident	Communication on ice conditions
Randy Best, Mud Lake Resident	Community coordination, team member for ice thickness survey
C-CORE	
Michael Lynch, B. Sc., Advanced Diploma GIS, Operations Manager	C-CORE Project Manager. Coordination with SEM, project control and reporting
Megan Lynch, B. Sc., Image Analyst	Satellite image analysis, generation of river ice products, ice floe analysis
Susan Carter, Diploma GIS, Satellite Order Desk	Plan, order and archive imagery
Hatch	
Wendy Warford, P. Eng.	Hydraulic analyses of ice floe concentration, thickness and velocity, report preparation
Tony Chislett, P. Eng.	QA/QC for hydraulic analyses results

2.3 Mud Lake Web Camera

In 2010, a web camera was established by the NLDEC/WRMD, in cooperation with LCP and Environment Canada, at the Mud Lake crossing on the north side of the Churchill River, near Happy Valley-Goose Bay, oriented upstream. Images from this web camera are transmitted by satellite and uploaded as near real time data to the NLDEC/WRMD web site at:

http://www.env.gov.nl.ca/wrmd/ADRS/v6/Template_Station.asp?station=NLENCL0004

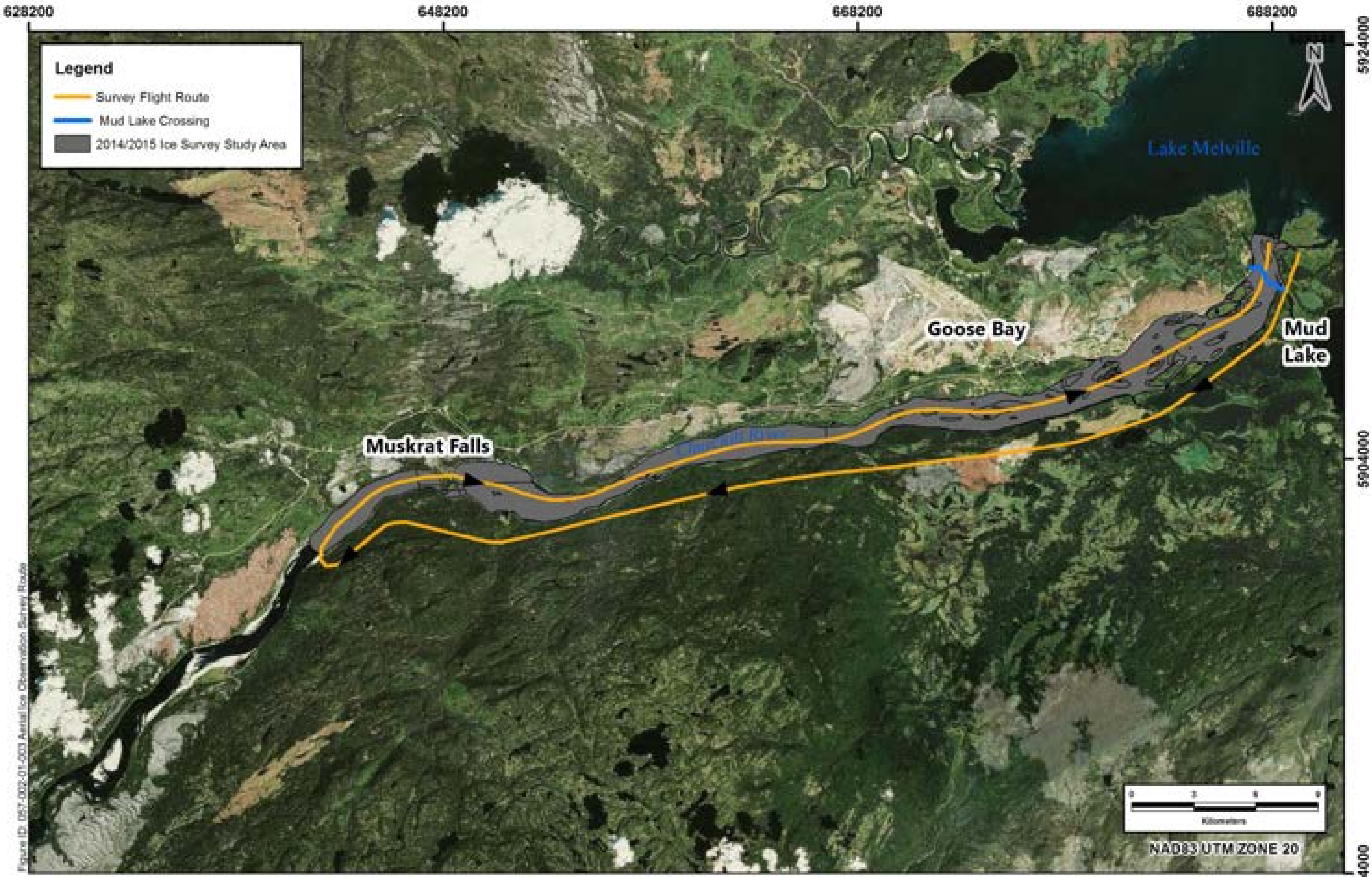
Photos taken by the web camera were consulted daily during planning for timing of aerial surveys and to document the freeze-up and break-up conditions. Images during the period from November 17 to 28, 2014, and May 5 to 22, 2015, were used to document and describe the freeze-up and break-up conditions at the Mud Lake crossing, respectively.

Additionally, SEM consulted with Mud Lake residents Mr. Jordan Hope and Mr. Randy Best for assistance and experience with respect to the timing of the aerial surveys to document the freeze-up and break-up processes. These individuals also provided SEM with the dates for the first snowmobile crossing on November 24, 2014, and the first boat crossing in May 18, 2015, to continue the time series for these important dates for the residents of Mud Lake.

2.4 Photographic Surveys

A key component of the ice survey program was the aerial ice observation survey which took place during both the freeze-up and break-up periods on the reach of the Lower Churchill River from Lake Melville up to Muskrat Falls (Figure 2.1).

During the ice freeze-up period, daily helicopter (Bell 206 Long Ranger) surveys were completed between November 22 to 25, 2014, to observe the ice conditions from Lake Melville, past Mud Lake and Goose Bay, and up to Muskrat Falls. The surveys were completed at approximately the same time each day (between 12:00 to 15:00) with the helicopter flying at the same altitude (800 to 1,200 m above sea level [masl]). The process for photographic documentation of the ice freeze-up had the helicopter travelling along the southern bank of the lower Churchill River while the SEM team took continuous side view photographs (Figure 2.2). On the return trip, the helicopter flew down the centre line of the river and the SEM team took photographs at approximately 2 km intervals, looking down river and encompassing views from bank to bank (Figure 2.3). Global Positioning System (GPS) locations were logged along the route at each photograph location to ensure consistency between photographs during the three day survey for the ice formation period. While at Mud Lake, additional photographs were taken of the potential locations where the Mud Lake Crossing was to be placed. A total of 850 photographs were taken during the freeze-up period (234 photos on November 22; 216 photos on November 23; 205 photos on November 24; and 195 photos on November 25).



PREPARED BY Golder Associates	Lower Churchill Ice Observation Studies	PREPARED BY SEM
Figure 2.1	AERIAL OBSERVATION SURVEY ROUTE	DATE 12/08/2015

Daily helicopter surveys with a Bell 206 Long Ranger were completed from May 17 to 19, 2015, during the ice break-up period to observe the ice conditions between Mud Lake and Muskrat Falls. The process for photographic documentation of the ice break-up was as described above with the helicopter flying at the same altitude (250 to 350 masl), except on May 19 when the helicopter had to maintain a lower altitude (150 masl) due to weather conditions (i.e. low ceiling) in the area. A total of 530 photographs were taken during the break-up period (182 photos on May 17; 176 photos on May 18; and 172 photos on May 19).

Figure 2.2 Example of a Photograph Taken From the Southern Bank of the Lower Churchill (Side View).

Figure 2.3 Example of a Photograph Taken From the Central Route Down the Lower Churchill River (Bank to Bank).

2.5 Ice Thickness Measurement at the Mud Lake Crossing

SEM completed the ice thickness measurements between February 9 and 10, 2015 after the Mud Lake crossing was completely frozen over. A total of ten locations were drilled using a gasoline powered auger along the ice crossing route as delineated by Mud Lake residents (Figure 2.4). The SEM team followed the delineated ice crossing route used by Mud Lake residents; the ice thickness was measured with a tape measure and a description of the ice condition was recorded.

Figure 2.4 Mud Lake Ice Crossing Route, February 2015.

2.6 Satellite Observations

During the 2014-2015 ice season, satellite images of the Churchill River near Mud Lake were acquired and interpreted by C-CORE. Satellite SAR images were acquired by CSK and used to monitor ice conditions. SAR images provided detailed ice surface textures and accurately delineated areas of open water. The images were processed to identify ice types and areas of open water which were used to assess ice cover variability on the lower Churchill River. The advantages of using SAR technology included the ability to "see" through cloud and fog, the system is relatively weather independent and data can be acquired day or night.

The river ice monitoring season occurred between November 23, 2014 and May 23, 2015. Images were acquired at an approximate frequency of every four days to cover the reach of river between Muskrat Falls and Mud Lake. Additional images were acquired daily at the Mud Lake crossing during ice freeze-up from November 25 to November 29, 2014, and break-up from May 5 to May 22, 2015.

A total of 60 images were acquired using the CSK constellation which consisted of four SAR satellites. Image orders required a primary and a secondary (back-up) plan. When a primary image was not acquired, the secondary image would then be tasked, which was typically 12 hours later. There were eight instances where the primary image was not acquired and their respective secondary image was acquired. Fourteen of the 60 images were high-resolution (5 m) and were used to monitor the Mud Lake area of the river, while the remaining 46 were medium resolution (30 m). Table 2.2 contains detailed specifications of the satellite images. A complete list of images processed for the Lower Churchill River ice monitoring survey is provided in Appendix A. Analyses of the satellite imagery for the freeze-up and break-up processes, as well as during the period of constant ice cover are provided in Appendices B, C and D, respectively.

Table 2.2 Satellite Image Specifications.

Satellite	Beam Mode	Spatial Resolution (m)	Image Width (km)	Number of Images
CSK	StripMap	5	30	14
CSK	ScanSAR Wide	30	100	46

Radar satellites are active sensors in that they transmit a signal to the Earth's surface and record the energy reflected back to the sensor, as backscatter, and pixel intensity within the image is proportional to the backscatter. The sensor is side looking, so most of the signal will be deflected away from the sensor on smooth surfaces such as smooth ice. Rough surfaces, such as found with an ice jam, will deflect the signal in all directions including back to the sensor, producing bright areas as seen in the images. Generally, surfaces with roughness or complex geometry have higher backscatter. Figure 2.5 depicts schematically, the surface scattering and volume scattering processes. In the surface scattering diagram, the ice surface roughness dictates how much of the incoming signal is deflected away from the satellite and how much is received. Areas of rough ice will cause more of the signal (backscatter) to be received by the satellite. These features are represented as white pixels in the image. Darker areas in images represent smooth surfaces where much of the signal is deflected away from the satellite. The second diagram illustrates how volume scattering occurs within ice containing air pockets and cracks.

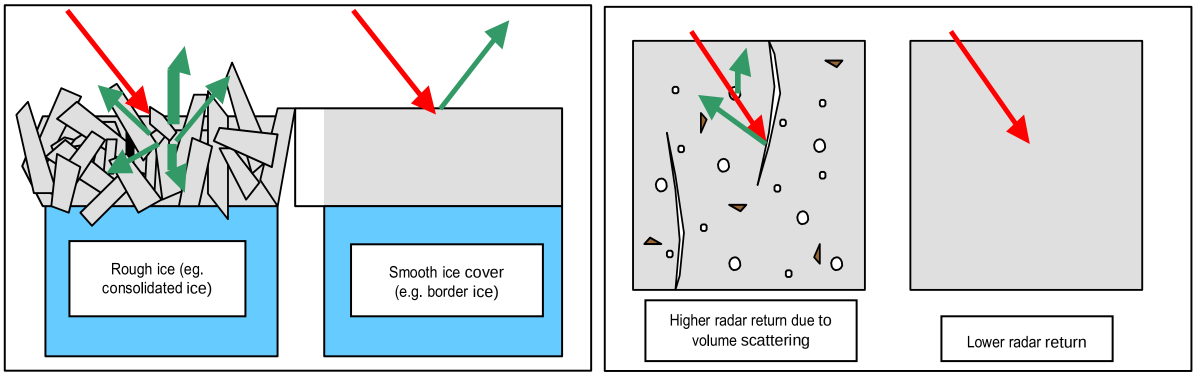


Figure 2.5 River Ice Scattering Mechanisms (Pelletier and Hicks 2003).

Image analysis included calibration, orthorectification, filtering and visual enhancement. Filter and enhancement techniques were unique to each image, due to different spatial resolutions, incidence angle and ice cover. Filters were used to remove noise and speckle, which are characteristic of SAR images. The choice of enhancement technique depended on weather conditions, ice textures and the amount of open water, all of which affected backscatter and the calibration results.

Late in the ice season, rough ice textures became smoother; resulting in less backscatter, to the point that ice began to resemble open water. Prior knowledge of weather conditions, recent satellite images and field data were important factors to aid in separating open water from water on ice. Water pooling on the surface of ice resulting from melting or rainfall appeared similar to open water. Resolution of the ambiguity was assisted by acquiring additional imagery from a satellite with a lower radar frequency. In May 2014, the ALOS-2 satellite was launched which has a lower frequency than CSK and thus could discriminate between ice with ponded water and open water. ALOS-2 data were poor at ice-typing (smooth versus rough ice) so they must be used in combination with CSK data.

The Ice Cover product is a map containing the calibrated, visually enhanced, orthorectified SAR image. The darker sections of the river are areas of smooth ice or open water. They may also be pools of water on ice, depending on the time of year and the recent weather conditions. Smooth surfaces appear the same within a SAR image prior to image processing, such as those described above. Figure 2.6 shows an example of an ice cover product from the November 23, 2014, SAR image.

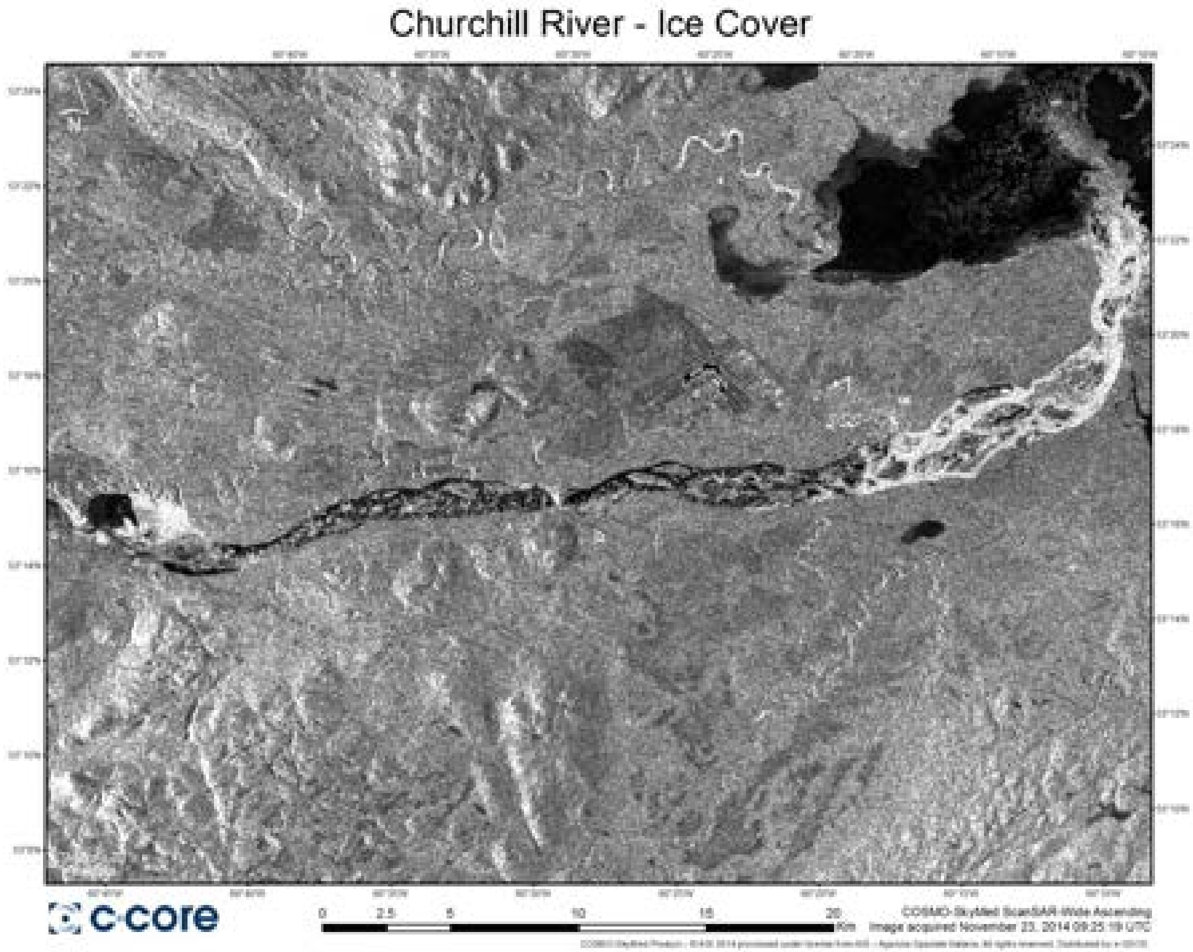


Figure 2.6 Ice Cover Product Created From the November 23, 2014, SAR Image.

The Ice Classification product is the result of classifying SAR backscatter. The three classes are: (i) open water or water on ice; (ii) non-consolidated or smooth ice surface; and (iii) consolidated or rough ice surface. Figure 2.7 shows an example of the Ice Classification product from the November 23, 2014, SAR image.

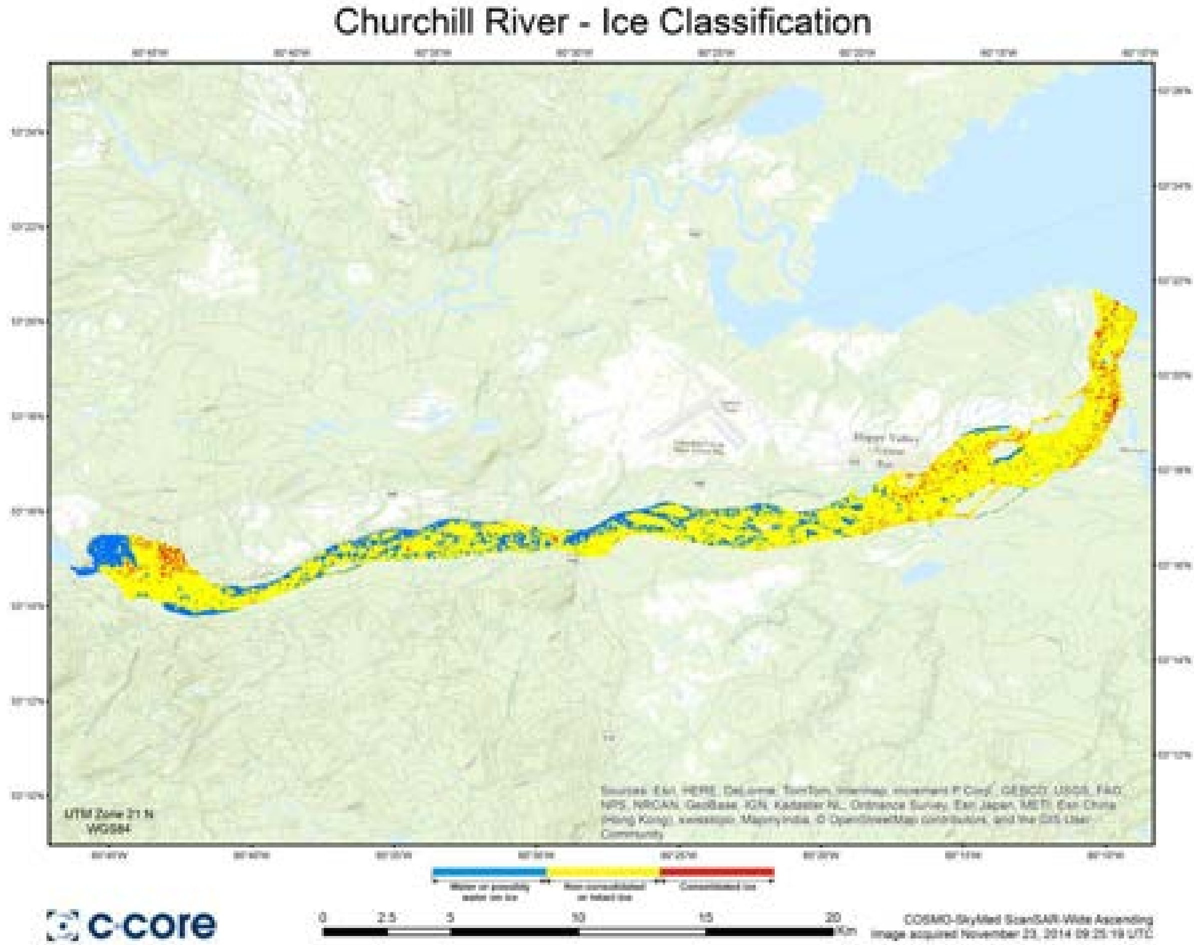


Figure 2.7 Ice Classification Product Created From the November 23, 2014, SAR Image.

The Change Detection product is the result of subtracting the previous image from the most recent image. The result is a product indicating where the ice surface backscatter has increased (yellow and red) and decreased (light blue and dark blue) as well as areas where no change (green) has occurred. This is a useful product for tracking ice break-up and freeze-up processes as well as sudden changes throughout the ice season due to sudden weather changes such as rain. Figure 2.8 shows an example of a Change Detection product for the comparison of images from November 23 and 24, 2014.

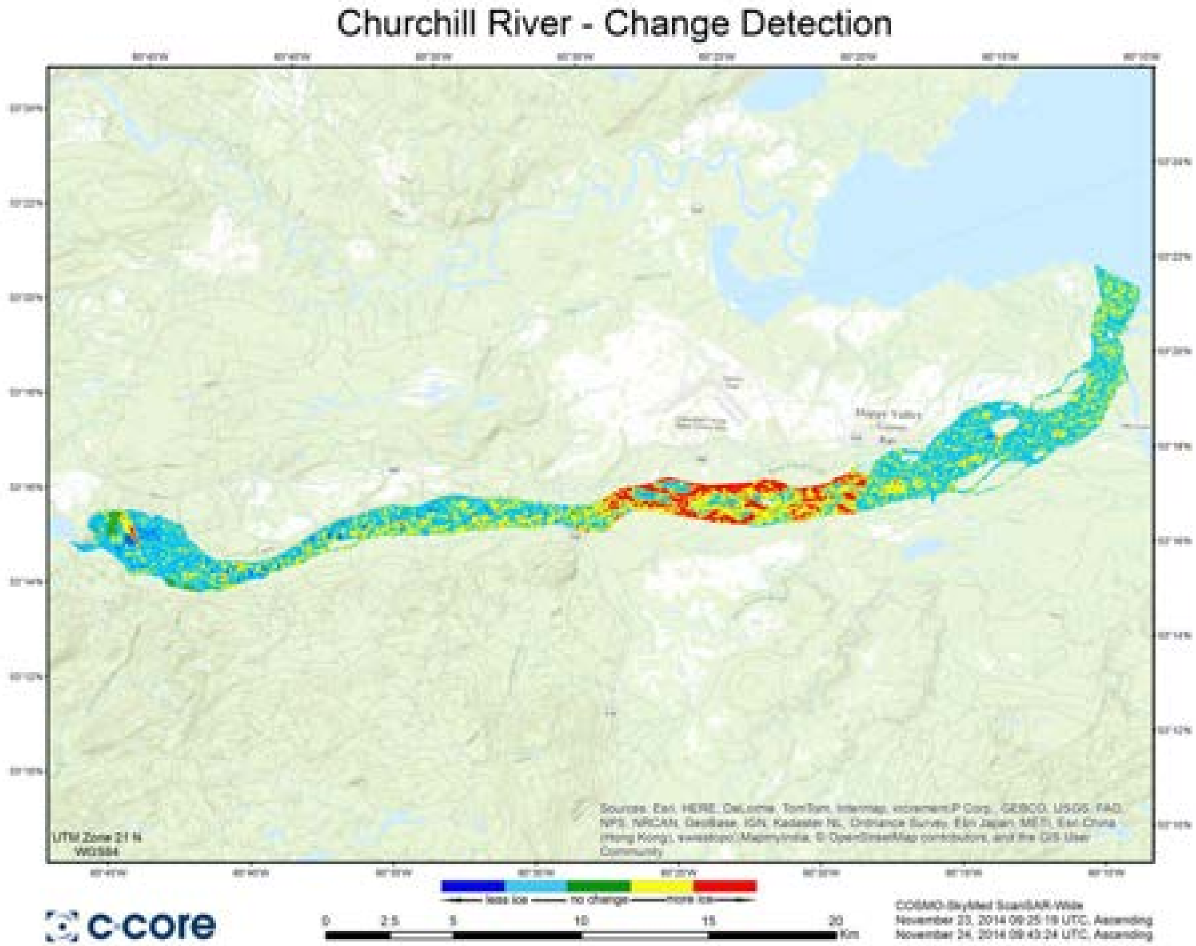


Figure 2.8 Change Detection Product Comparing the November 23 and 24, 2014, SAR Images.

2.7 Ice Floe Concentration

An ice floe concentration analysis was performed on aerial photographs taken during the helicopter ice surveys (see Section 2.4) during freeze-up and break-up periods for the purpose of studying ice concentrations in the reach between Muskrat Falls and Mud Lake. Separate analyses were conducted for ice break-up and freeze-up periods. Photographs were chosen based on several factors including site locations that would represent as much of the river as possible, image clarity (glare and reflection) and photograph perspective. A total of 40 photographs were processed: 18 for freeze-up and 22 for break-up. The photograph sites chosen for break-up and freeze-up are similar, with the purpose of studying the changing ice cover at the same locations. Figure 2.9 shows the locations where selected photographs were collected for the analyses. The photographs analyzed and the interpreted products, during freeze-up and break-up are provided in Appendices E and F, respectively.

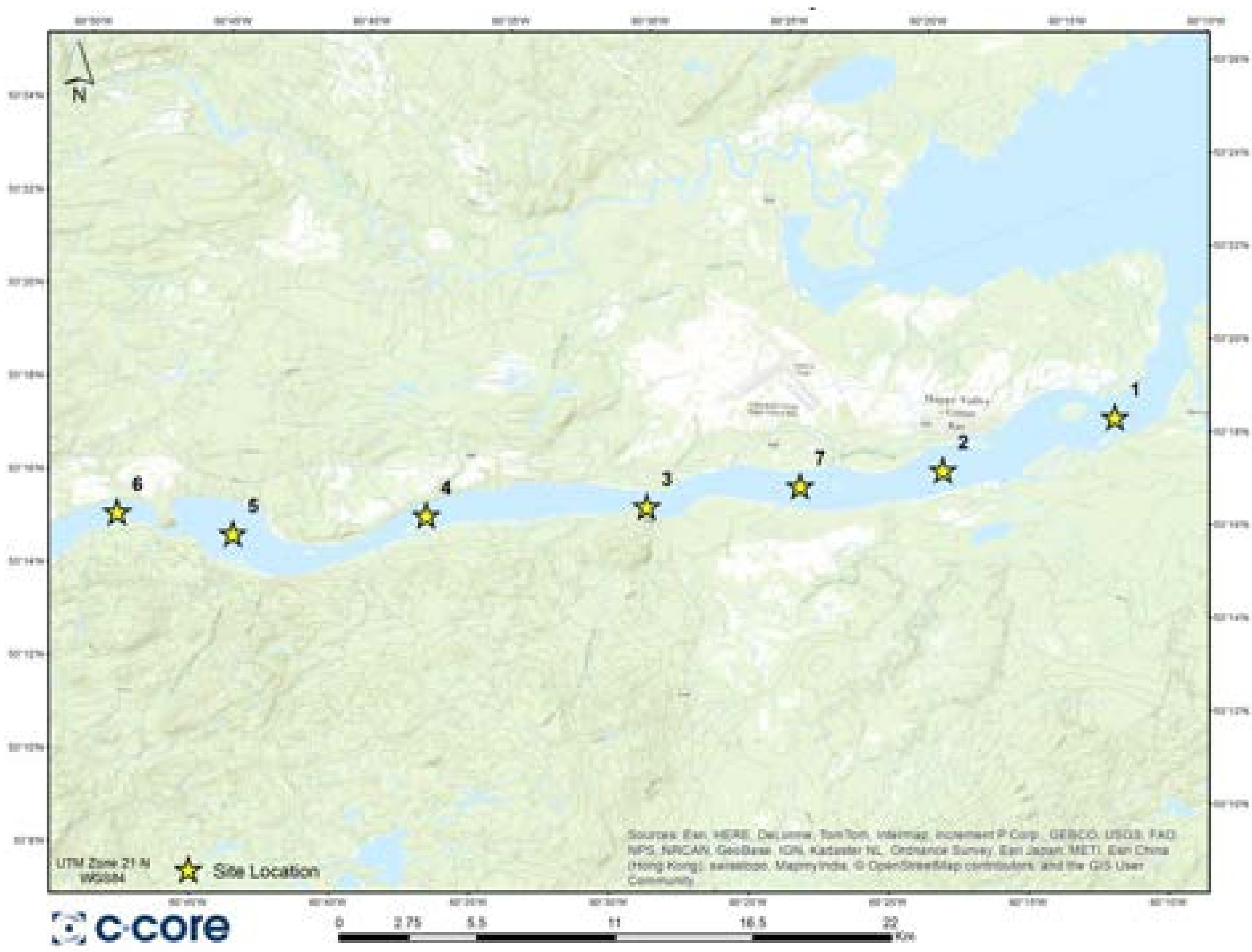


Figure 2.9 Photograph Locations During Freeze-Up and Break-Up in the 2014-2015 Ice Season.

2.8 Volumetric Flow Rate of Ice

The ice cover on the lower Churchill River typically forms via an ice bridge near Mud Lake and propagates upstream from this location. The formation of the ice bridge is dependent on the volumetric flow rate of ice arriving at the bridging location. Estimates of the volumetric flow rate of ice can be made through observation of the following three variables:

- Ice floe concentration (i.e., area of ice coverage);
- Ice floe thickness; and
- Ice floe velocity.

The purpose of determining the volumetric flow rate of ice is to estimate the relative contribution of ice originating upstream of Muskrat Falls to that arriving at the bridging location near Mud Lake. Consequently, ice flow rate estimates were made at the following four locations:

- Upstream of Muskrat Falls;
- Downstream of Muskrat Falls;
- Near Blackrock Bridge; and
- Near the Mud Lake ice bridge crossing.

Ice floe concentration estimates (see Section 2.7) were obtained through the analysis by C-CORE of photographs taken from a helicopter during the freeze-up process (see Section 2.4). Ice floe concentration estimates (in percent) for the period between the start of ice formation and the formation of the ice bridge at Mud Lake were derived for the above four locations.

The first step in the process was to select a representative portion of the photograph for analysis. Stationary border ice was excluded as well as other parts of the photograph that appeared to be influenced by the following factors: sun reflection on the water surface; reflection from the windshield of the helicopter; shadows on the water surface; wind induced riffles; and ice fog. Next, unsupervised classification was used to create an ice class and an open water class. The number of pixels for the water and ice classes were then summed and converted to percentages.

In the absence of direct measurements, the Stefan Equation (USACE 2002) was used to estimate ice floe thickness for the purpose of volumetric ice flow rate calculation. The Stefan Equation is:

$$\text{Thickness in mm} = C\,(DDF)^{0.5}$$

Where:

C = coefficient (taken as 15 mm*degree Celsius $^{-0.5}$ * day $^{-0.5}$ for average rivers with snow)

DDF = cumulative degree days of freezing

Ice floe velocity, as average cross sectional velocity, was estimated using the latest version (2010) of the hydraulic model (HEC-RAS) for the Churchill River, as developed in 2010 by Hatch. The average daily flow in the Churchill River, taken from the Water Survey of Canada gauging site at Churchill River above Upper Muskrat Falls (03OE001) for November 22, 2014, was 1,953 $m^3{\cdot}s^{-1}$ and this was used in the analyses. The width of the flow channel on the interpreted photographs was estimated from satellite imagery collected on November 22, 2014, and subsequently used in the hydraulic model analysis.

3.0 RESULTS

3.1 Mud Lake Web Camera

Archived images from the NLDEC/WRMD web camera at the Mud Lake crossing site were provided to SEM (on CD) and have been used to document and describe the freeze-up and break-up conditions at this location.

The freeze-up sequence for the period from November 17 to 28, 2014, is shown in Figures 3.1 and 3.2. Open water conditions were recorded at the web camera site on November 17, with ice developing along the river margins on November 18. Increasing concentrations of ice arriving from upstream locations were observed on November 20, with concentrations increasing over the period from November 20 to 24. The ice bridge crossing was considered formed on November 24, and Mud Lake residents began delineating the crossing on that date, which was the first date for snowmobile crossing in the 2014-2015 ice season.

Similarly, the break-up sequence for the period from May 5 to 22, 2015, is shown in Figures 3.3 and 3.4. The images from May 5 through 8, demonstrated that the river was still frozen over completely with some melting areas first starting to appear on May 14 and 15. From May 15 to 18, open water sections became evident with increasing amounts of open water appearing over this period. There were extensive areas of open water on May 18 and 19. The river was free of large ice pans by May 19, with some ice rafting on the river margins. The amount of rafted ice decreased incrementally from May 20 to 22. The date of first crossing by boat was May 18. The duration of the break-up was about five to seven days, which is consistent with observations from previous years and as reported by SNC-Lavalin (2012a) for 2012 (six days) and for 2014 (seven days, SEM 2014).

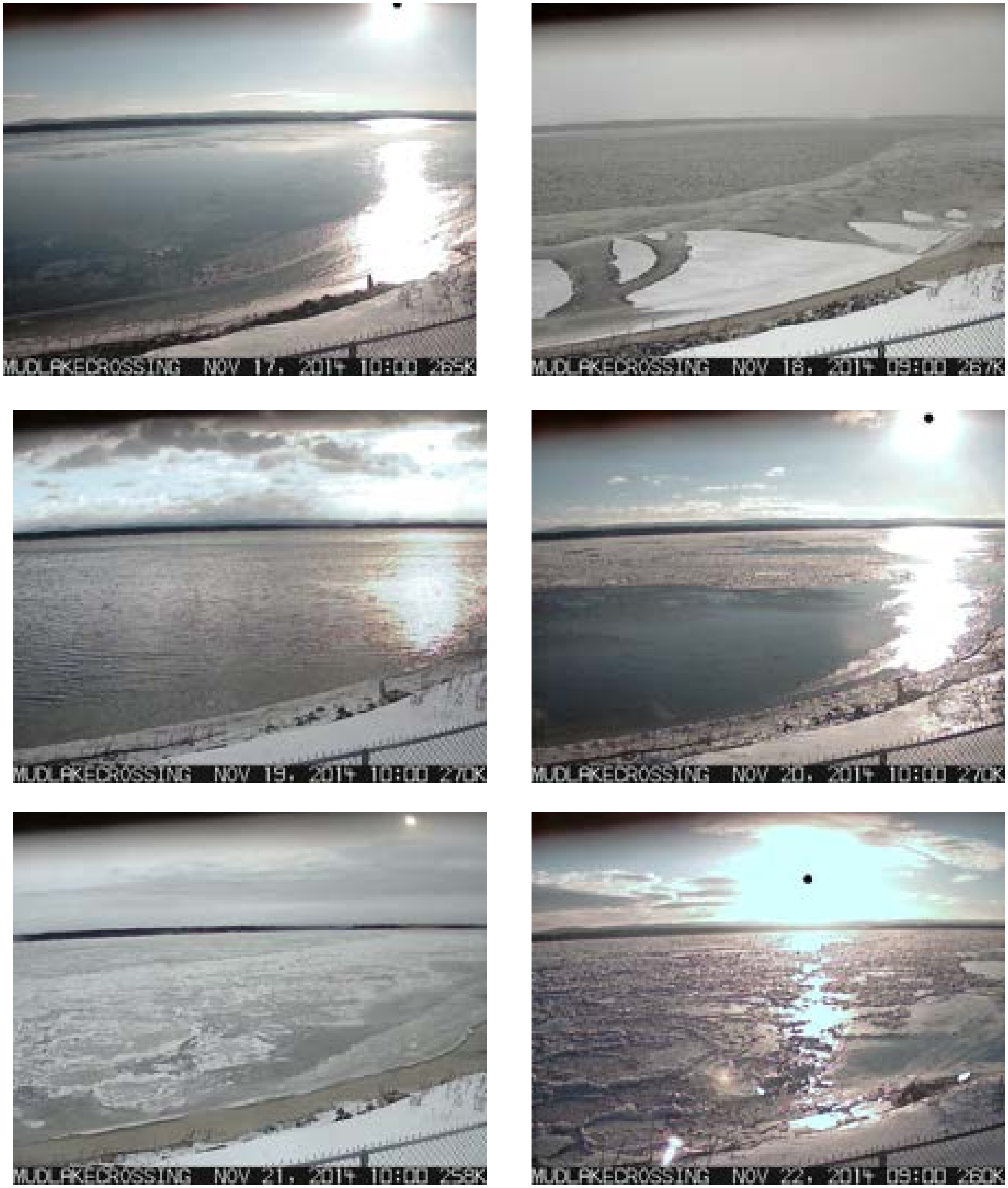


Figure 3.1 Mud Lake Web Camera Images During the Freeze-Up Process, November 17 - 22, 2014.

Figure 3.2 Mud Lake Web Camera Images During the Freeze-Up Process, November 23 - 28, 2014.

Figure 3.3 Mud Lake Web Camera Images During the Break-Up Process, May 5 - 16, 2015.

Figure 3.4 Mud Lake Web Camera Images During the Break-Up Process, May 17 - 22, 2015.

3.2 Photographic Surveys

Photographs were collected during the ice freeze-up period from November 22 to 25, 2014. Similarly, photographs were obtained during the ice break-up period from May 17 to 19, 2015. At the end of each day the SEM team catalogued all photographs and evaluated the products to determine if any modifications in protocol were required. Select photographs have been included in Appendices E and F to illustrate the progression of freeze-up and break-up. Field reports for the aerial ice observation surveys are provided in Appendix G. All of the photographs taken during this period are available upon request.

The photographs were used by C-CORE to estimate ice floe concentration during the freeze-up and break-up processes (Section 3.4). Hatch used the results of the ice floe concentration analyses in the estimation of the volumetric flow rate of ice (Section 3.7).

3.3 Timing of Freeze-Up and Break-Up

The timing of the freeze-up and break-up processes during the 2014-2015 ice season, in comparison to the long-term data record, and in comparison to the last ten years of record, is provided in Table 3.1. The date of freeze-up, as indicated by the day of the first snowmobile crossing, was November 24, 2014. The date of break-up, as indicated by the date of the first boat crossing, was May 18, 2015. The date of freeze-up was four days earlier than the long-term average (November 28), eight days earlier than the freeze-up in 2013, and 13 days earlier than the average for the last ten years (December 7). Similarly, the date of break-up was four days later than the long term average (May 14), close to the break-up in 2014 (May 17), but nine days later than the average for the last ten years (May 9). It is apparent over the last ten years that the date of freeze-up has been later, with the latest date on record in 2011 (January 7), with 2014 being the earliest freeze-up date over the last ten years. Similarly, the average date of break-up has been getting earlier over the last ten years (May 9) in comparison to the long-term average (May 14), with the earliest date of break-up on record in 2010 (April 20). The early freeze-up date in 2014, and late break-up date in 2015, resulted in total ice covered period of 176 days in the 2014-2015 ice season.

Table 3.1 Long Term Record of Freeze-Up and Break-Up at the Mud Lake Crossing.

Date	Freeze-Up (first snowmobile crossing)	Break-Up (first boat crossing)
1972	22-Nov-72	5-Jun-72
1973	-	-
1974	-	-
1975	25-Nov-75	30-May-75
1976	17-Nov-76	17-May-76
1977	30-Nov-77	15-May-77
1978	19-Nov-78	27-May-78
1979	24-Nov-79	14-May-79
1980	29-Nov-80	17-May-80
1981	23-Dec-81	15-May-81
1982	28-Nov-82	1-May-82
1983	29-Nov-83	14-May-83
1984	23-Nov-84	15-May-84
1985	18-Nov-85	28-May-85
1986	13-Nov-86	7-May-86
1987	28-Nov-87	23-Apr-87
1988	1-Dec-88	12-May-88
1989	24-Nov-89	15-May-89
1990	1-Dec-90	22-May-90
1991	2-Dec-91	26-May-91
1992	19-Nov-92	27-May-92
1993	13-Nov-93	17-May-93
1994	27-Nov-94	22-May-94
1995	29-Nov-95	11-May-95
1996	1-Dec-96	4-May-96
1997	23-Nov-97	24-May-97
1998	30-Nov-98	12-May-98
1999	23-Nov-99	10-May-99
2000	25-Nov-00	11-May-00
2001	4-Dec-01	14-May-01
2002	22-Nov-02	22-May-02
2003	7-Dec-03	17-May-03
2004	7-Dec-04	18-May-04
2005	11-Dec-05	8-May-05
2006	4-Dec-06	4-May-06
2007	30-Nov-07	17-May-07
2008	5-Dec-08	7-May-08

Table 3.1 Long Term Record of Freeze-Up and Break-Up at the Mud Lake Crossing. (Cont'd)

Date	Freeze-Up (first snowmobile crossing)	Break-Up (first boat crossing)
2009	9-Dec-09	18-May-09
2010	7-Jan-11	20-Apr-10
2011	2-Dec-11	12-May-11
2012	2-Dec-12	15-May-12
2013	2-Dec-13	1-May-13
2014	24-Nov-14	19-May-14
2015	TBD	18-May-15
Long Term Average	**28-Nov**	**14-May**
Average (last 10 Years)	**7-Dec**	**09-May**

3.4 Ice Floe Concentration

An ice floe concentration analysis was performed on 40 aerial photographs taken during helicopter ice surveys during freeze-up and break-up periods for the purpose of studying ice concentrations in the reach between Muskrat Falls and Mud Lake. A total of 40 photographs were processed: 18 for freeze-up and 22 for break-up. Photos were selected based on several factors including site location that would represent as much of the river width as possible, image clarity (glare and reflection), and photo perspective. The photo sites for break-up and freeze-up were similar, as the objective was to document changing ice conditions at the same locations.

The results included a processed image with ice cover and open water classes with their respective area of coverage. Only the portion of the river where ice was flowing was classified, and border ice was not included. The analysis was performed using a Fuzzy K Means classification algorithm (Bezdek 1973) with an image mask isolating the classification to the river and areas of the river where separation between water and ice was possible. Filters were used to remove isolated, classified pixels. Figure 3.5 shows an example photograph and Figure 3.6 shows the resulting classification.

Figure 3.5 Example Photograph from the Aerial Ice Survey.

Figure 3.6 Example of a Classified Photograph from the Aerial Ice Survey.

During the image analysis there were some issues encountered. Reflections of vegetation on open water, shadow from overhanging banks and trees along the river, limited visibility caused by fog and photographs taken looking towards the horizon caused difficulty during classification. As a result, some images could not be processed to accurately distinguish between water and ice in some areas.

3.4.1 Freeze-Up Period

Aerial surveys were conducted on November 22 to 25, 2014, and a total of 850 photographs were collected. From these, three were selected from each of the November 22, 23 and 25 surveys for analysis. Photographs were chosen to cover the same sections of the river every day to determine changing ice cover. The site locations from which photos were selected are provided in Figure 2.9 and Table 3.2 contains the results of the analysis. The ice and water coverage were calculated from the number of pixels in each photograph and presented as a percentage. The percent of ice cover increased from November 22 to 23 from (mean ± Std. Dev.) 51.3 ± 25.1% ice cover to 57.3 ± 29.0% ice cover. The proportion of ice cover decreased on November 25 (47.9 ± 41.1%), largely due to declining ice cover (3.4%) at location #6, just above Muskrat Falls. The proportion of ice cover generally decreased from the river mouth in an upstream direction on all three sampling dates, except at locations #5 and #6, where the proportion of ice increased. The detailed ice floe analysis results for the photographs taken during freeze-up, including the classified images, are provided in Appendix E.

Table 3.2 Ice Cover and Open Water Percent Coverage for Freeze-Up.

Date	Site #	Photo #	Water (%)	Ice (%)	Latitude	Longitude
November 22	1	5095	5.47	94.53	53°17'57.672"	60°10'59.124"
November 22	2	5135	51.23	48.77	53°16'14.232"	60°19'17.226"
November 22	3	5176	62.36	37.64	53°15'35.184"	60°28'37.344"
November 22	4	3797	76.02	23.98	53°14'57.402"	60°36'49.230"
November 22	5	3749	35.97	64.03	53°14'50.808"	60°45'42.066"
November 22	6	3836	61.71	38.29	53°14'18.162"	60°45'38.550"
November 23	1	3919	7.13	92.87	53°18'7.836"	60°10'52.236"
November 23	2	3954	9.56	90.44	53°16'8.352"	60°19'27.804"
November 23	3	3994	43.33	56.67	53°15'29.844"	60°29'15.612"
November 23	4	4024	78.73	21.27	53°14'57.228"	60°36'44.412"
November 23	5	4058	55.63	44.37	53°13'48.810"	60°43'31.320"
November 23	6	4079	61.94	38.06	53°15'5.880"	60°47'39.168"
November 25	1	4334	8.95	91.05	53°18'17.994"	60°10'39.576"
November 25	2	4367	6.07	93.93	53°16'11.994"	60°18'47.682"
November 25	3	4402	32.57	67.43	53°15'31.404"	60°29'40.338"
November 25	4	4426	85.28	14.72	53°14'53.082"	60°37'4.800"
November 25	5	4452	83.16	16.84	53°14'4.884"	60°44'49.398"
November 25	6	4459	96.60	3.40	53°14'29.640"	60°46'51.936"

3.4.2 Break-Up Period

Aerial surveys were conducted daily from May 17 to May 19, 2015, and a total of 530 photographs were collected. From these, three were selected each day for analysis. Photographs were chosen to cover the same sections of the river every day to determine changing ice cover. The site locations from which photos were selected are provided in Figure 2.9 and Table 3.3 contains the results of the analysis. Two images were analyzed from location #5 for May 17, as an internal quality assurance check on the differences between images collected at the same time. The percent of ice cover decreased from May 17 to 19, ranging from (mean ± Std. Dev.) 73.2 ± 33.7% to 42.4 ± 38.5. The proportion of ice cover was consistently lowest at location #6, just above Muskrat Falls. The detailed ice floe analysis results for the photographs taken during break-up, including the classified images, are provided in Appendix F.

Table 3.3 Ice Cover and Open Water Percent Coverage for Break-Up.

Date	Site #	Photo #	Water (%)	Ice (%)	Latitude	Longitude
May 17	1	904	10.07	89.93	53°17'57.672"	60°10'59.124"
May 17	2	932	8.34	91.66	53°16'14.232"	60°19'17.226"
May 17	3	966	50.82	49.18	53°15'35.184"	60°28'37.344"
May 17	4	991	27.42	72.58	53°14'57.402"	60°36'49.230"
May 17	5	1036	0.99	99.01	53°14'50.808"	60°45'42.066"
May 17	5	1037	13.89	86.11	53°14'50.808"	60°45'42.066"
May 17	6	1032	99.91	0.09	53°14'18.162"	60°45'38.550"
May 17	7	947	2.99	97.01	53°16'23.665"	60°23'52.593"
May 18	1	1091	22.97	77.03	53°17'57.672"	60°10'59.124"
May 18	2	1117	38.52	61.48	53°16'14.232"	60°19'17.226"
May 18	3	1148	59.67	40.33	53°15'35.184"	60°28'37.344"
May 18	4	1170	92.59	7.41	53°14'57.402"	60°36'49.230"
May 18	5	1209	4.74	95.26	53°14'50.808"	60°45'42.066"
May 18	6	1202	99.86	0.14	53°14'18.162"	60°45'38.550"
May 18	7	1133	5.51	94.49	53°16'23.665"	60°23'52.593"
May 19	1	1268	93.79	6.21	53°17'57.672"	60°10'59.124"
May 19	2	1292	35.12	64.88	53°16'14.232"	60°19'17.226"
May 19	3	1326	26.42	73.58	53°15'35.184"	60°28'37.344"
May 19	4	1350	95.50	4.50	53°14'57.402"	60°36'49.230"
May 19	5	1374	4.80	95.20	53°14'50.808"	60°45'42.066"
May 19	6	1381	99.99	0.01	53°14'18.162"	60°45'38.550"
May 19	7	1403	47.46	52.54	53°16'23.665"	60°23'52.593"

3.5 Ice Thickness Measurement at the Mud Lake Crossing

An ice thickness measurement and core interpretation survey was completed between February 9 and 10, 2015. A total of ten locations were augured along the ice crossing route as delineated by Mud Lake residents (Figure 3.7). The SEM team followed the delineated ice crossing route used by Mud Lake residents and collected ice thickness measurements at these ten locations. Sample sites were located a safe distance from the route so as to not obstruct traffic or cause any safety concerns, but close enough to get a good representation of the ice conditions along the route.

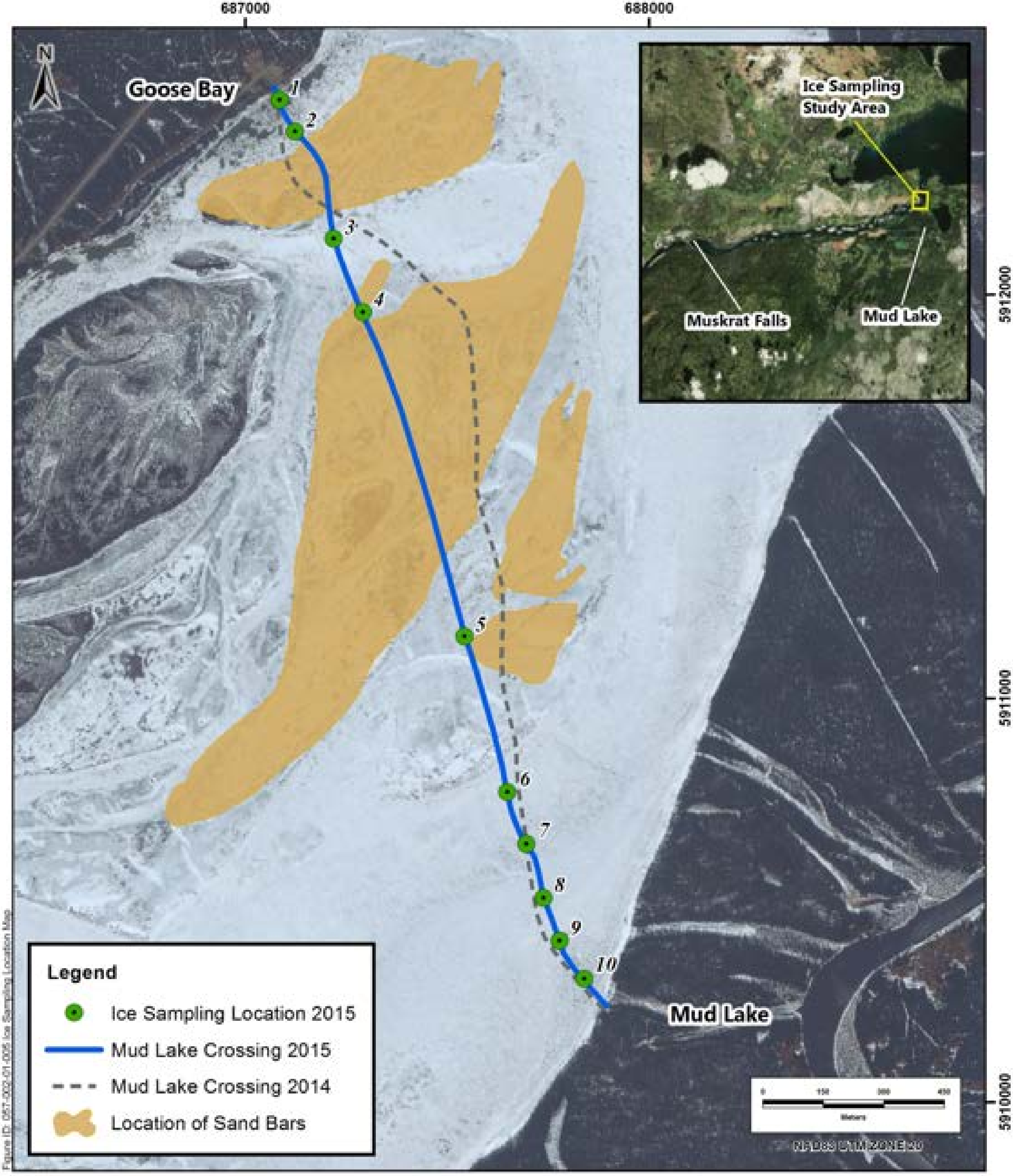


Figure ID: 087-002-01-005 Ice Sampling Location Map

PREPARED BY Golder Associates	**Lower Churchill Ice Observation Studies**	PREPARED BY SEM
Figure 3.7	Ice Sampling Location Map	DATE **12/08/2015**

Holes in the ice were drilled using a gasoline powered auger. At each location the ice thickness was measured with a tape measure and a description of the ice condition recorded. Thickness measurements and associated notes are provided in Table 3.4.

Table 3.4 Ice Thickness Measurements and Ice Quality Along the Mud Lake Crossing in February, 2015.

Location ID	Easting	Northing	Ice Thickness (cm)	Snow Depth (cm)	Notes
1	687084	5912481	80	75	Ice solid throughout.
2	687123	5912403	81	96	Ice rough on surface. Ice solid throughout.
3	687218	5912137	84	118	Ice solid throughout. Second auger extension required.
4	687291	5911955	65	82	Channel between sandbars located by local hire Randy Best. Ice solid throughout.
5	687543	5911152	74	81	Ice solid throughout.
6	687649	5910767	90	80	Ice solid throughout.
7	687696	5910638	85	80	Ice solid throughout. Water welled-up through hole after auguring.
8	687739	5910504	95	90	Ice rough on surface. Ice solid throughout. Could hear water running.
9	687778	5910398	100	70	Ice solid throughout. Air pocket.
10	687839	5910304	72	20/90	Ice solid throughout. Very slushy under snow. Snow depth variable due to slush.

The ice thickness from the ten locations was variable, averaging 82.6 cm ± 10.7 (Std. Dev.), ranging from 65 to 100 cm and was solid throughout. Snow cover was considerable, ranging from 20 to 118 cm. In comparison, ice thickness in 2014 averaged 85.9 cm, was much more variable ranging from 45 to 120 cm, and at many locations ice was considered to be soft and slushy (SEM 2014). Snow cover in 2014 ranged from 10 to 70 cm and there was a slush layer below the snow ranging from 0 to 50 cm. The consistent thickness and solid ice condition in 2015 was attributed to the extreme cold conditions and good snow cover.

3.6 Satellite Image Analyses

This section provides an overview of the lower Churchill River ice conditions from freeze-up to break-up in the 2014-2015 ice season. Ice cover, classification and change detection products derived from SAR images from the ice monitoring program are provided in Appendices B, C and D.

C-CORE worked closely with SEM to estimate when break-up and freeze-up would occur. Local knowledge, weather data, webcam images and freely available satellite image data were some of the tools used to assist with estimating the times of these events. Image plans were created and modified to adjust to the freeze-up and break-up times.

3.6.1 Freeze-Up Period

Appendix B contains ice products for ice freeze-up in the Mud Lake area. Satellite river ice monitoring of the lower Churchill River began on November 23, 2014, using high and medium resolution SAR images focusing on freeze-up in the Mud Lake area. Images were then acquired almost daily up until December 3, 2014. Ice cover, ice classification and change detection products were produced for all of the images with the exception that a change detection product was not produced for the first image, as there was no previous image for comparative analysis.

Freeze-up occurred about two weeks earlier this year than last year (SEM 2014). Weather conditions, webcam images and local knowledge were used to help time the acquisition of the first high resolution image. Attempts were made to order more high resolution SAR images but the satellite high resolution data collection was not available at the time. Medium resolution images were planned as a replacement so that freeze-up would be captured.

The image acquired on November 23, 2014, showed suspended ice between Muskrat Falls and Happy Valley-Goose Bay. Downstream of Happy Valley-Goose Bay, the ice was consolidated due to the ice cover in Lake Melville. There were areas of open water which can be identified in the ice classification product. The remaining SAR image products showed the accumulation continuing until the ice cover became stable and consolidated on December 3. The change detection results showed specific areas of ice accumulation and the spatial extent of ice coverage. Change detection analysis was restricted to respective medium and high resolution image pairs.

3.6.2 Break-Up Period

Appendix C contains ice products for ice break-up on the lower Churchill River. The first high resolution image used for break-up monitoring of the Mud Lake area was acquired on May 7, 2015. A total of ten images were acquired to monitor the Mud Lake area during break-up.

Open water first appeared in the river originating from Mud Lake and along the north side of the Churchill River, just east of Happy Valley-Goose Bay, on May 10. Ice cover conditions remained the same until May 14, 2015, where new leads developed and existing leads widened. The ice cover rapidly deteriorated beginning May 16, 2015. Most of the river was ice free, with the exception of the section just below Muskrat Falls, by May 23. The ice below Muskrat Falls was extremely thick and this is typically the last area in the lower reach of the Churchill River to become ice free.

3.6.3 Seasonal Monitoring

Appendix D contains the ice products for seasonal monitoring of the Mud Lake area. The satellite river ice monitoring continued with 41 medium resolution SAR images of the lower Churchill River between Muskrat Falls downstream to Mud Lake. Ice cover, ice classification and change detection products were derived from image analysis for each of the 41 images. The first medium resolution image was acquired on December 4, 2014. Acquisitions continued at a frequency of approximately every four days up to and including May 23, 2015.

Figure 3.8 shows daily minimum and maximum air temperatures between November 20, 2014, and May 23, 2015. SAR image analyses determined that a correlation existed between lower backscatter from ice features and warmer air temperatures. The image analyses for December 1, 2014, for example, found the ice appeared brighter than on November 28, 2014, due to warmer temperatures on November 30, and December 1, 2014. This trend was observed again later in the ice season with the April 14, 2015 image, due to temperatures reaching 12°C the previous day. Warmer temperatures cause surface ice to melt, reducing the roughness of the ice surface, and therefore, reducing the amount of backscatter received by the satellite. Subsequent cold temperatures will freeze any water on the ice surface, increasing backscatter.

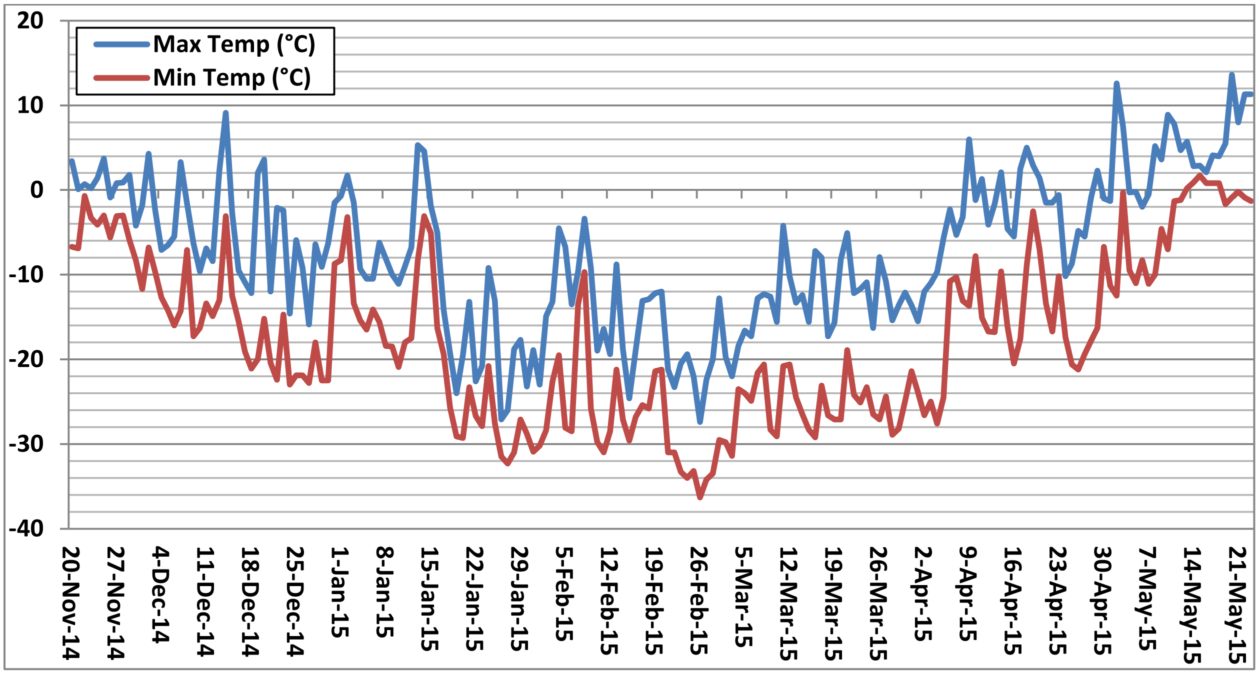


Figure 3.8 Daily Minimum and Maximum Air Temperatures During the 2014-2015 Ice Season.

3.7 Volumetric Flow Rate of Ice

Estimates of ice floe concentration were made available by C-CORE to Hatch for use in the analysis of volumetric flow rate of ice. Photographs taken during the helicopter survey conducted on November 22, 2014, were also used in this analysis. The average air temperature at Goose Bay Airport on November 22 was -10.15°C. Ice floe concentration estimates are outlined in Table 3.5 and associated images are provided in Appendix E.

Table 3.5 Ice Floe Concentration Estimates, Lower Churchill River, November 22, 2014.

Location	Ice Floe Concentration Estimates (%)
Upstream of Muskrat Falls	38.29
Downstream of Muskrat Falls	64.03
Near Blackrock Bridge	37.64
Near Mud Lake	94.53

Historical average daily temperatures at Goose Bay Airport were used to determine the cumulative degree days of freezing (DDF) to November 22, 2014, from the start of winter. Winter was assumed to begin on the first day of the first five day period with average daily temperatures remaining below zero. The cumulative DDF from the start of winter to November 22, was approximately 103.5 and the associated ice thickness was 0.15 m. For the purpose of this analysis, and in the absence of more reliable estimates, the ice thickness at each of the four analyzed locations was assumed to be equal.

Flow velocities for November 22, 2014, assuming the average daily flow of 1,953 $m^3 \cdot s^{-1}$, are provided in Table 3.6. Although flow velocity varies throughout each cross section, the velocities are assumed to be representative of the surface (i.e., ice floe) velocity. The flow regime downstream of Muskrat Falls is irregular and it is possible that ice floes located in the northern most part of the open channel are exposed to lower flow velocities.

Table 3.6 Ice Floe Velocity Estimates, Lower Churchill River, November 22, 2014.

Location	Ice Floe Velocity Estimate (m/s)
Upstream of Muskrat Falls	2.44
Downstream of Muskrat Falls	0.22
Near Blackrock Bridge	0.55
Near Mud Lake	0.38

To calculate the volumetric ice flow rate, the width of the open channel at each location must be estimated. To ensure consistency, channel width estimates were made using the same photographs that were provided to C-CORE for ice flow concentration estimation, as shown in Appendix E. The resultant volumetric ice flow rates are provided in Table 3.7.

Table 3.7 Volumetric Ice Flow Rate Analysis Results, Lower Churchill River.

Location	Width of Open Channel (m)	Ice Floe Concentration (%)	Ice Floe Thickness (m)	Ice Floe Velocity (m/s)	Volumetric Ice Flow Rate ($m^3 \cdot s^{-1}$)
Upstream of Muskrat Falls	430	38.29	0.15	2.44	61.2
Downstream of Muskrat Falls	910	64.03	0.15	0.22	19.7
Near Blackrock Bridge	260	37.64	0.15	0.55	8.2
Near Mud Lake	830	94.53	0.15	0.38	45.1

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2014-2015 Ice Observation Survey
Mud Lake Crossing, Lower Churchill River
LC-EV-107

Report Appendices

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August 25, 2015

APPENDIX A

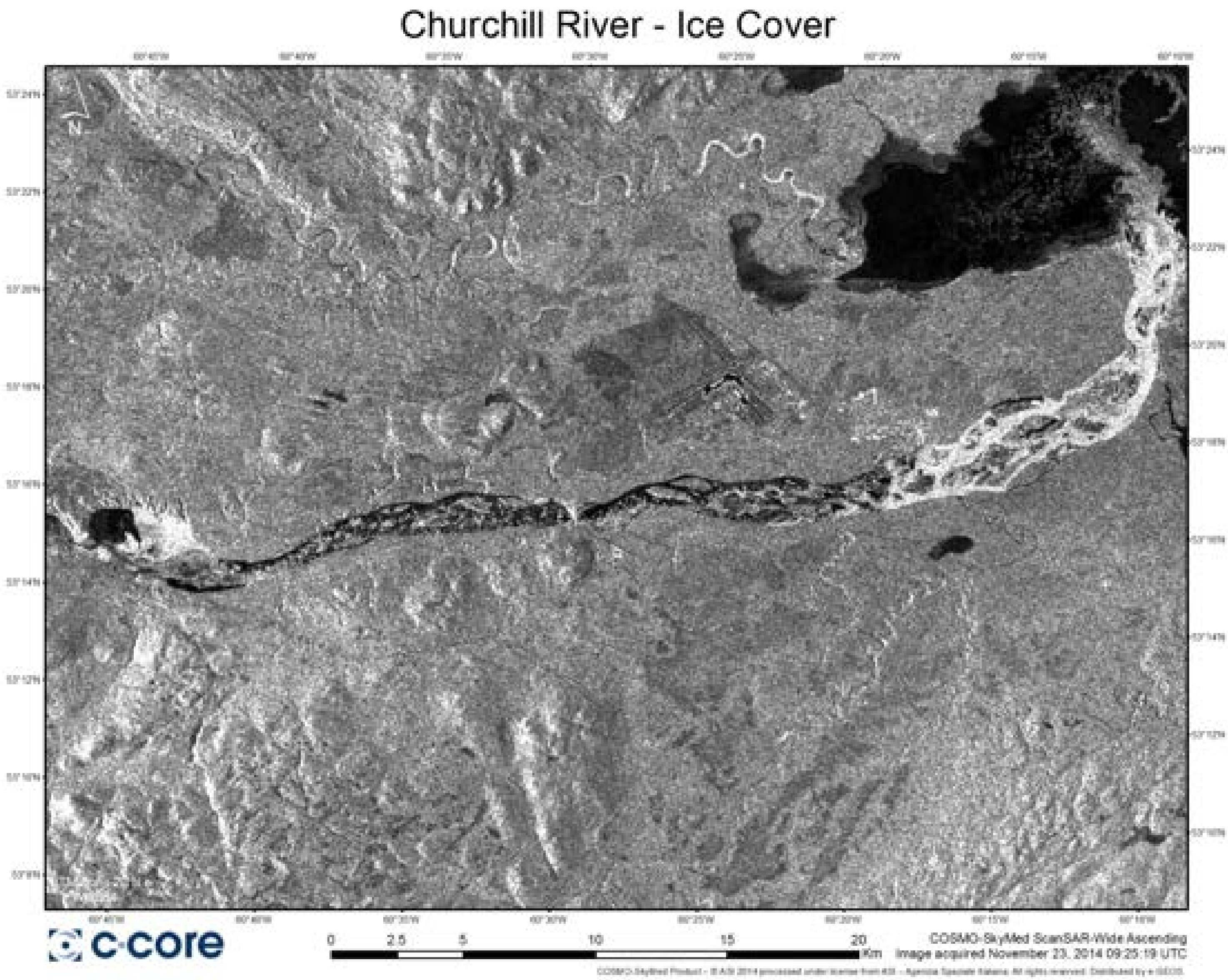
Satellite Image Acquisition Schedule

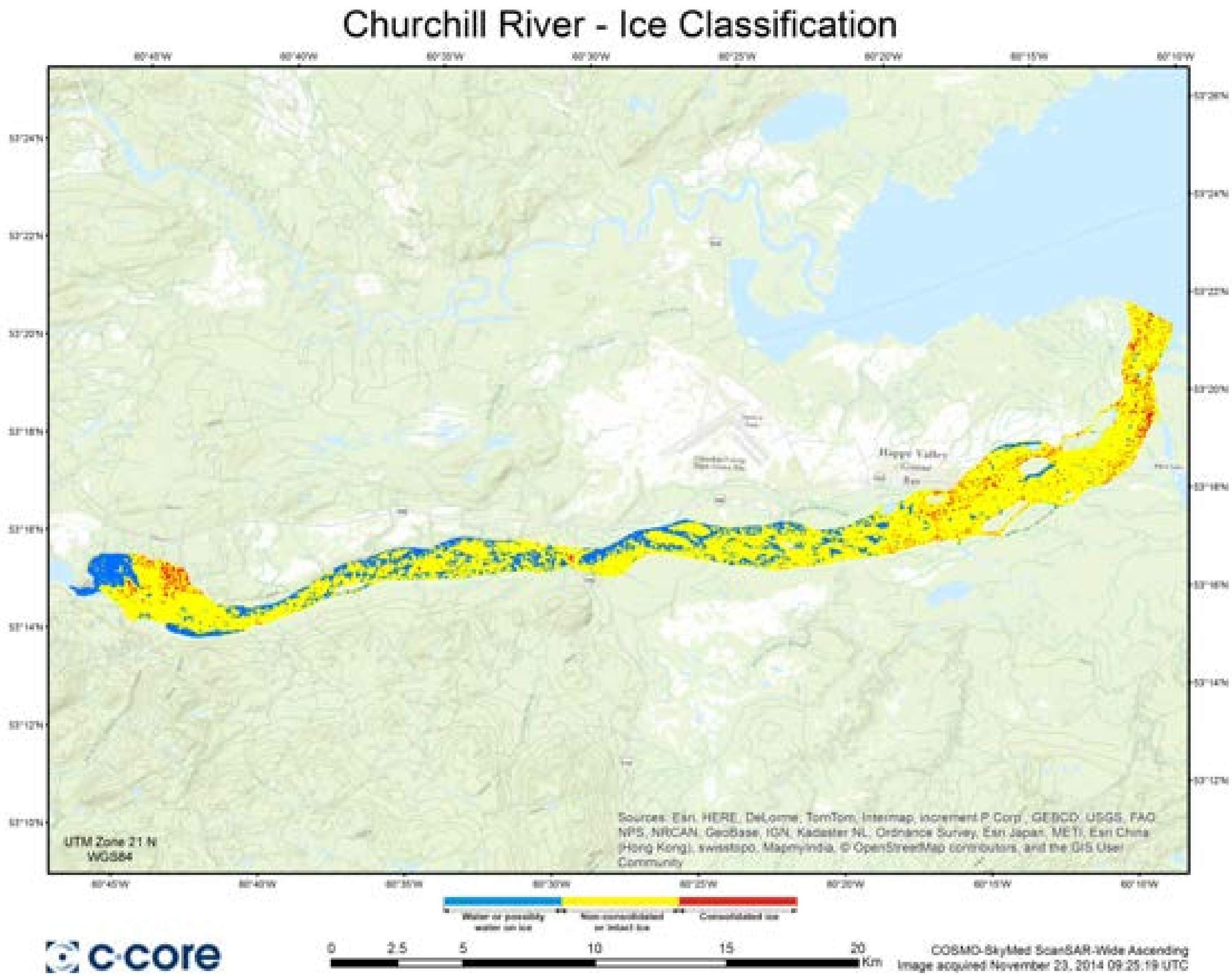
Date	Time (UTC)	Spatial Resolution (m)	Area

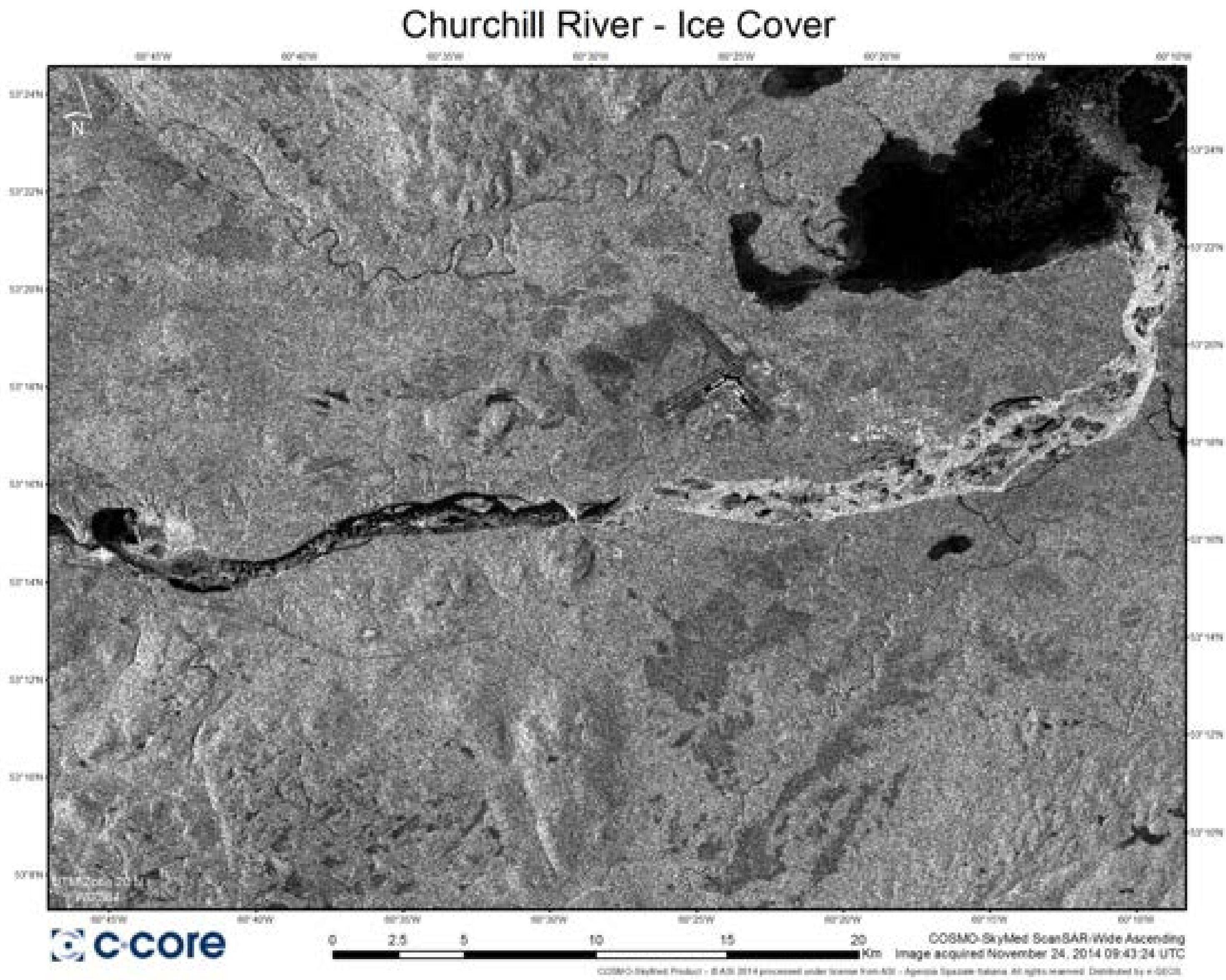
Date	Time (UTC)	Spatial Resolution (m)	Area

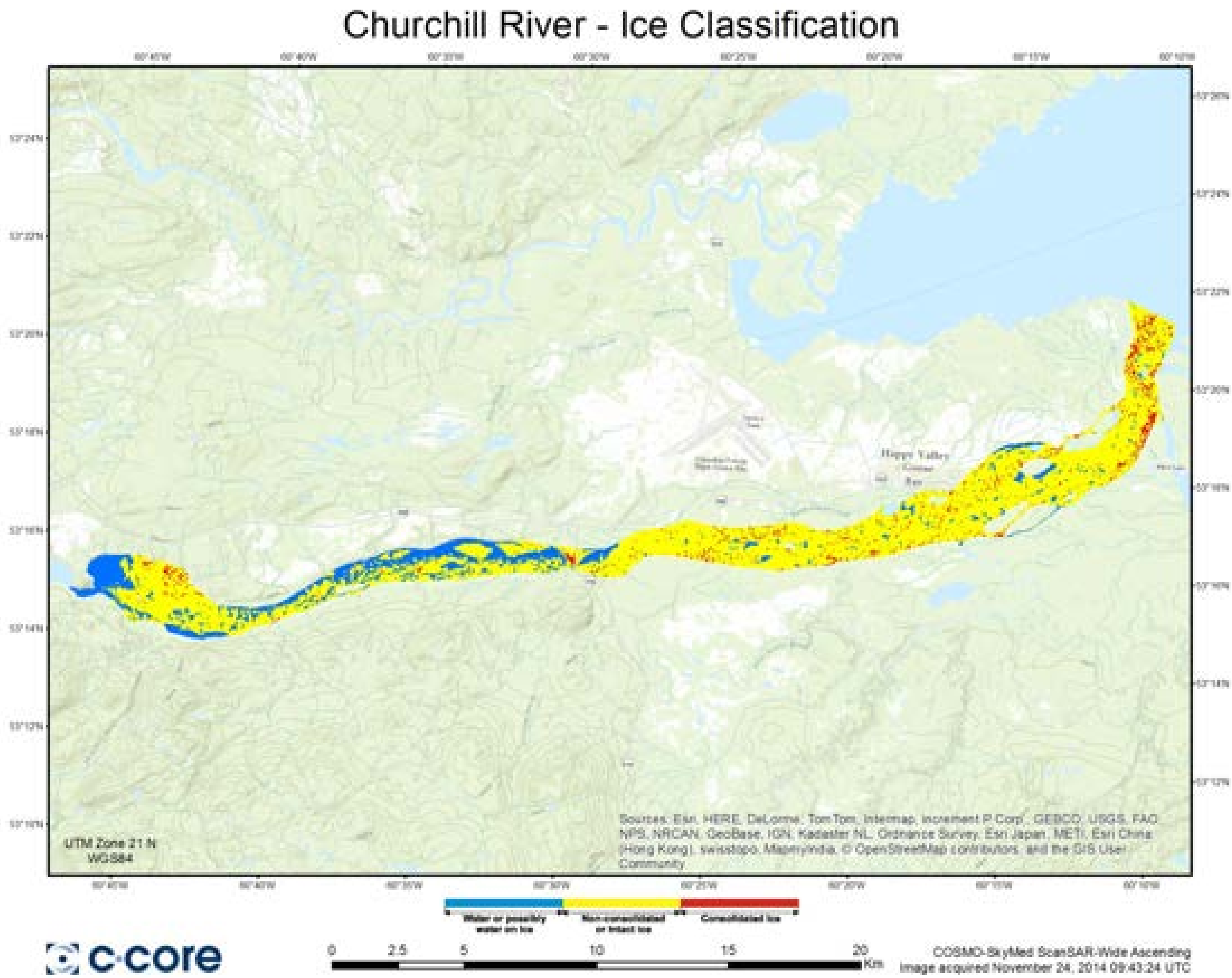
APPENDIX B

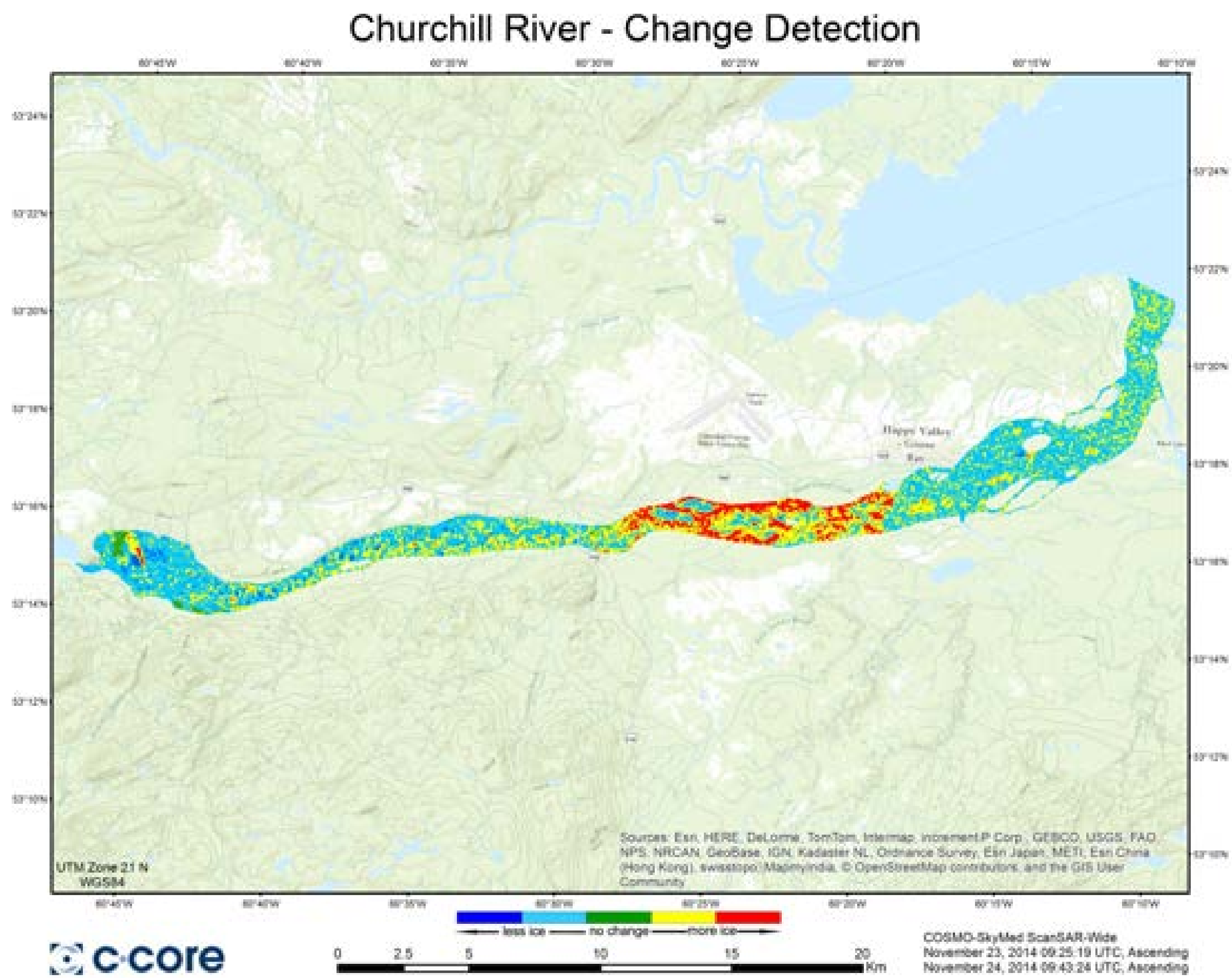
Mud Lake Freeze-up Satellite Imagery


Churchill River - Ice Cover
c·core
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired November 23, 2014 09:25:19 UTC

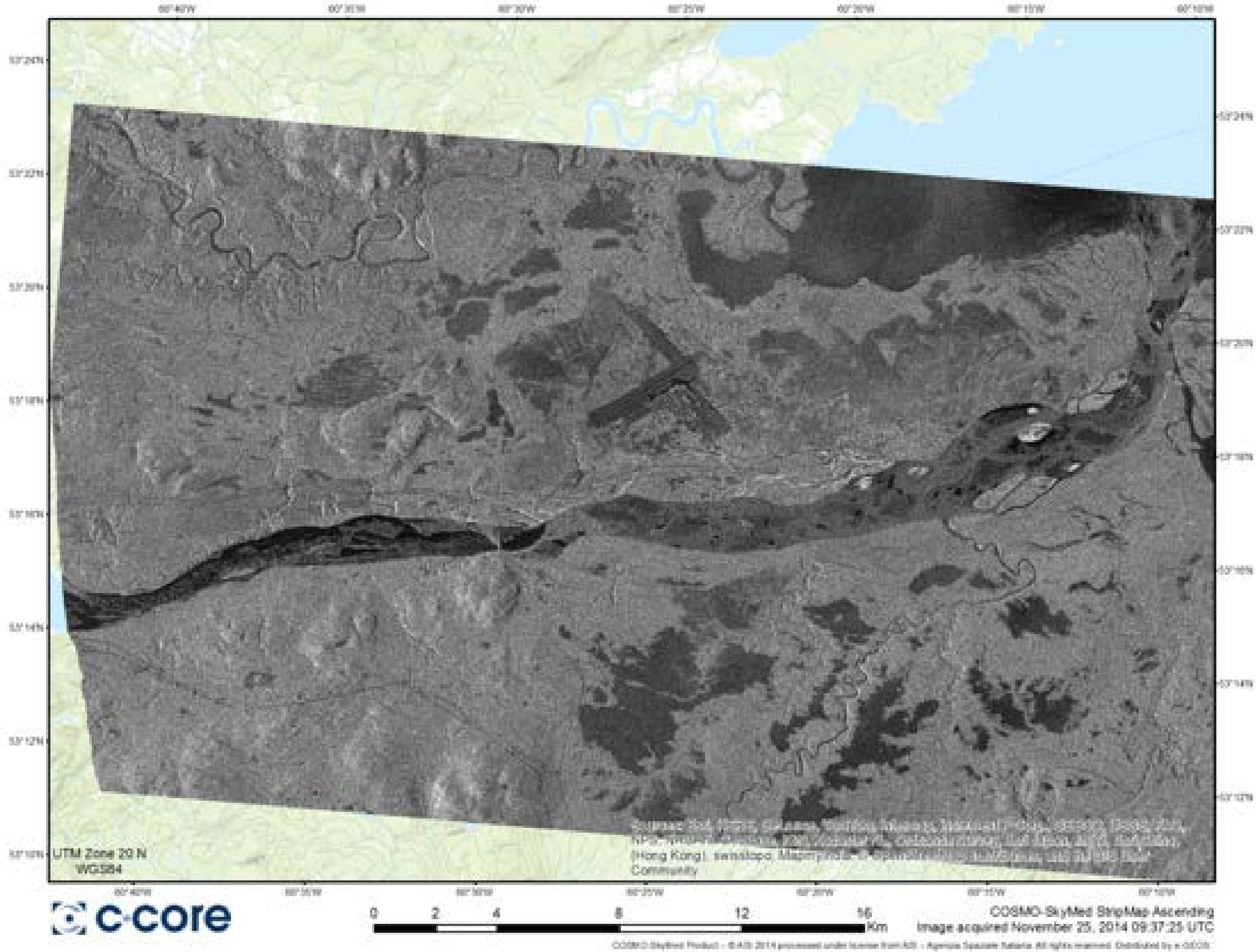

Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired November 23, 2014 09:25:19 UTC

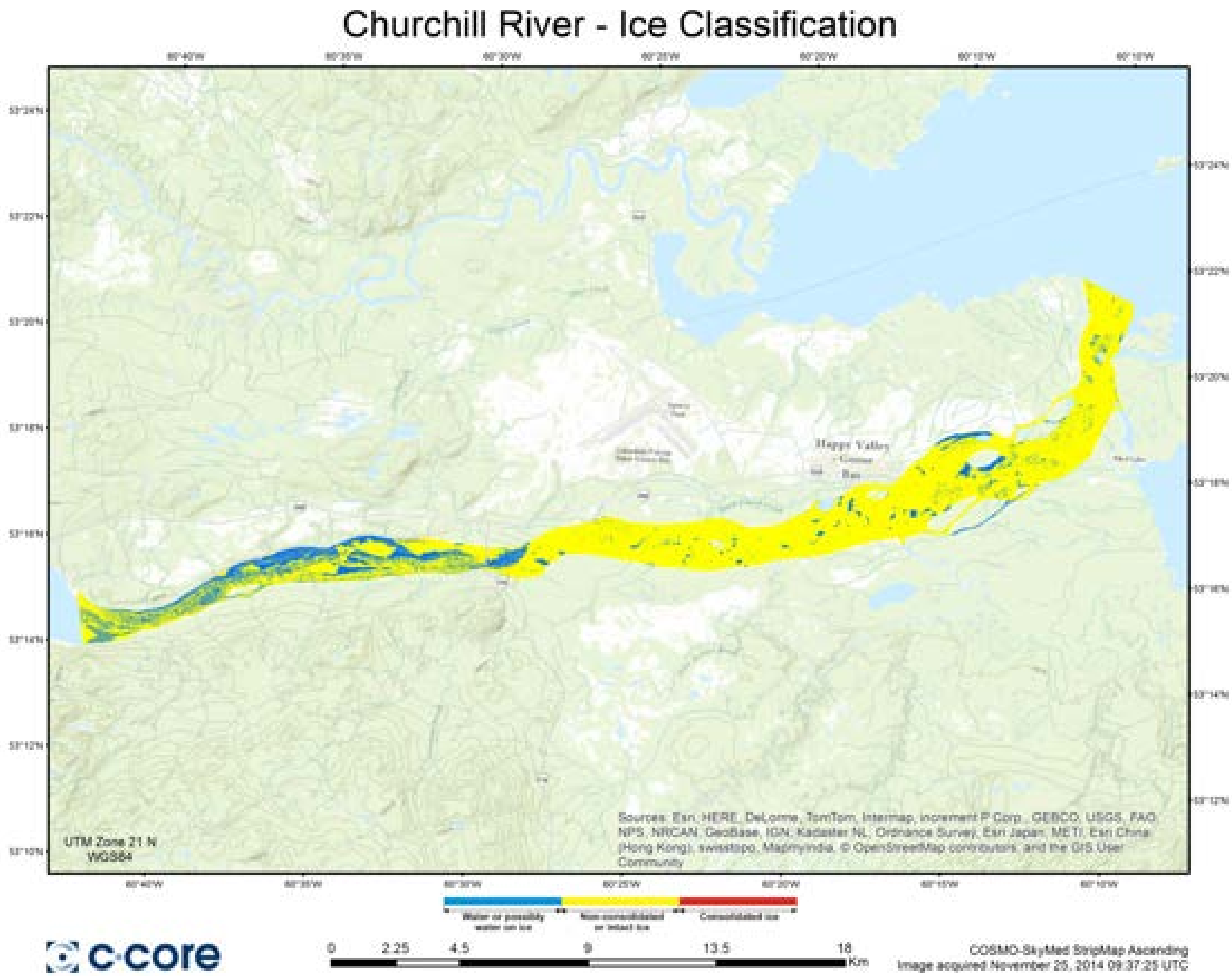

Churchill River - Ice Cover
N
c-core
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired November 24, 2014 09:43:24 UTC


Churchill River - Ice Classification
Happy Valley Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
c-core
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired November 24, 2014 09:43:24 UTC

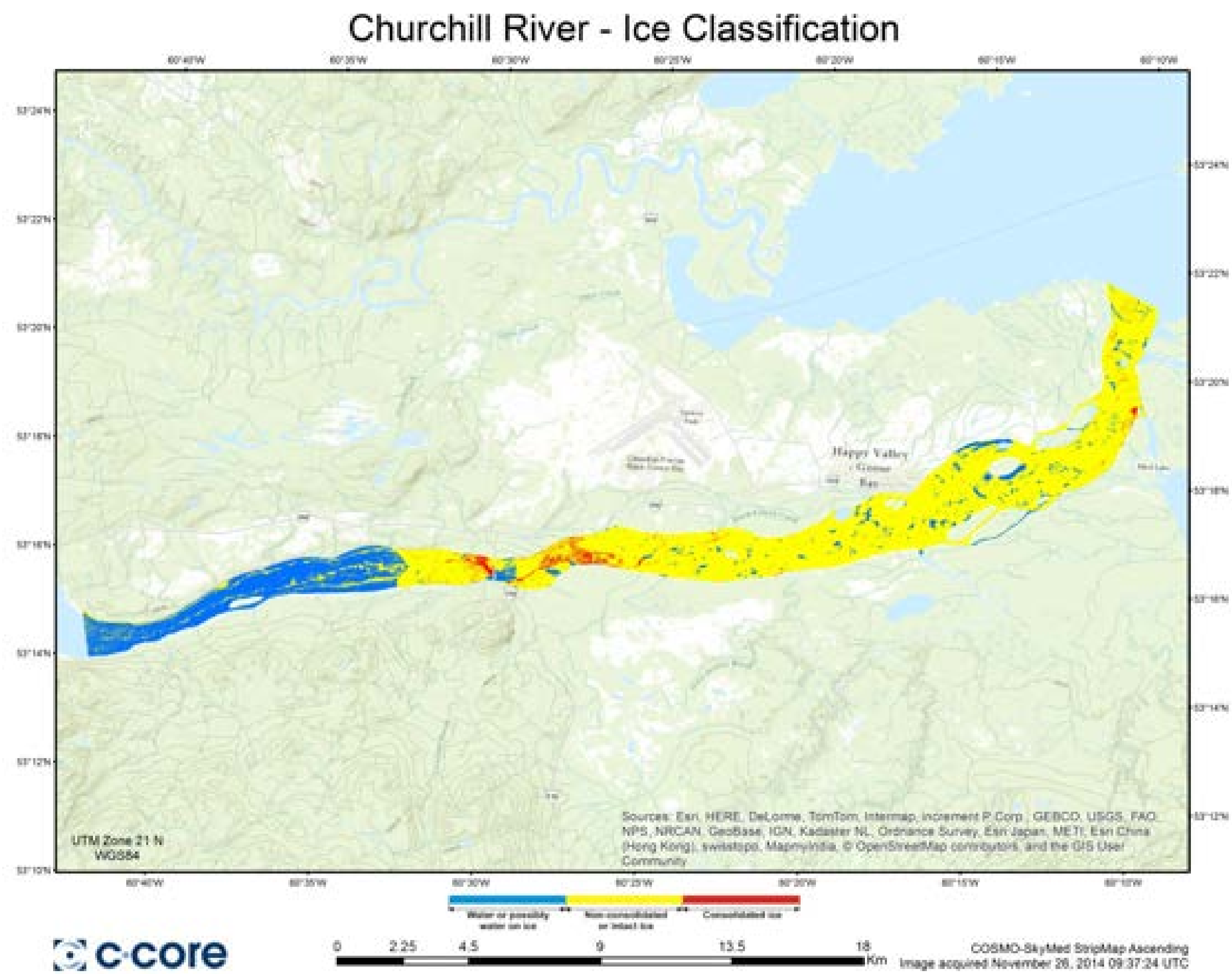

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
November 23, 2014 09:25:19 UTC, Ascending
November 24, 2014 09:43:24 UTC, Ascending

Churchill River - Ice Cover

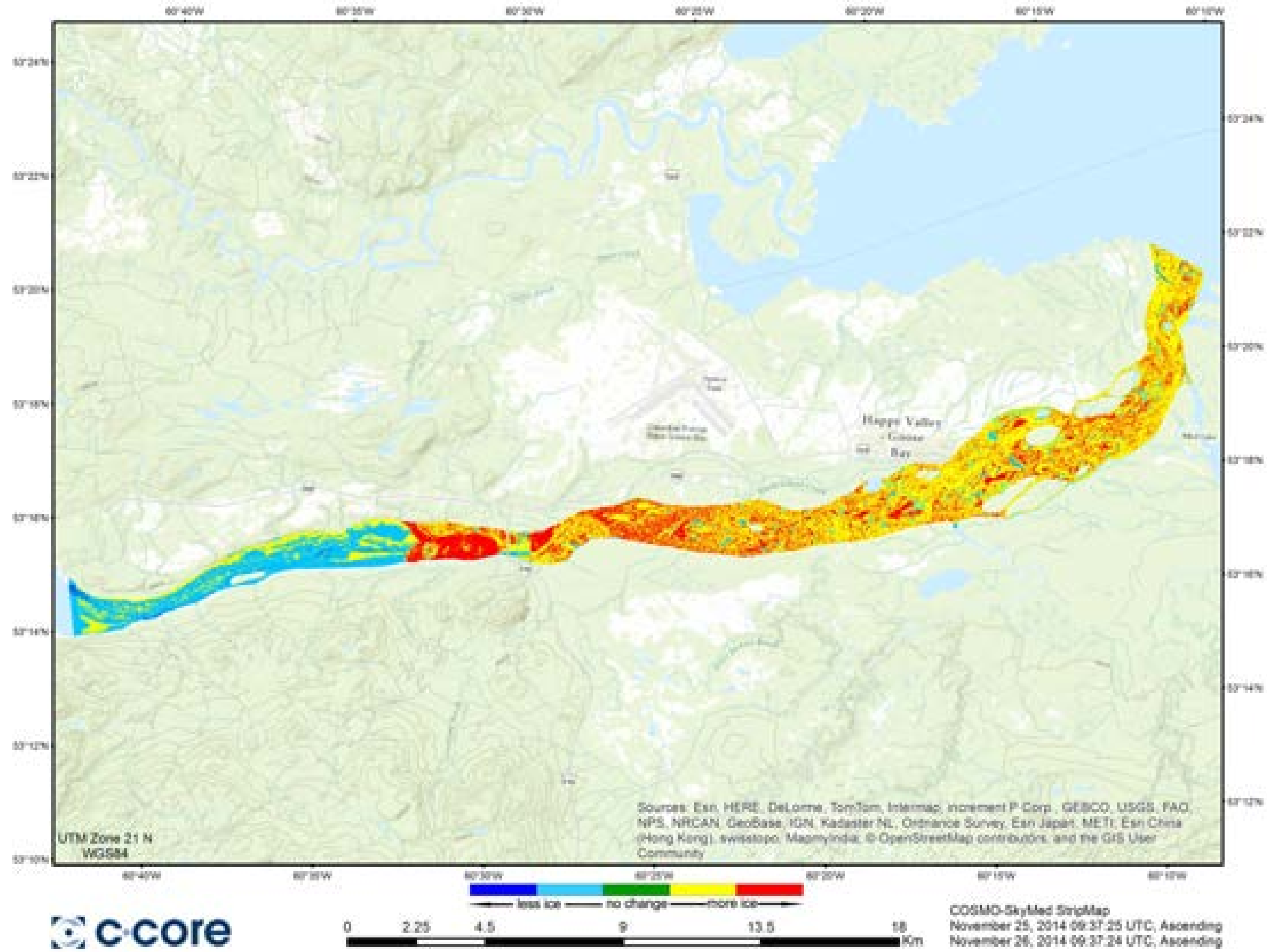


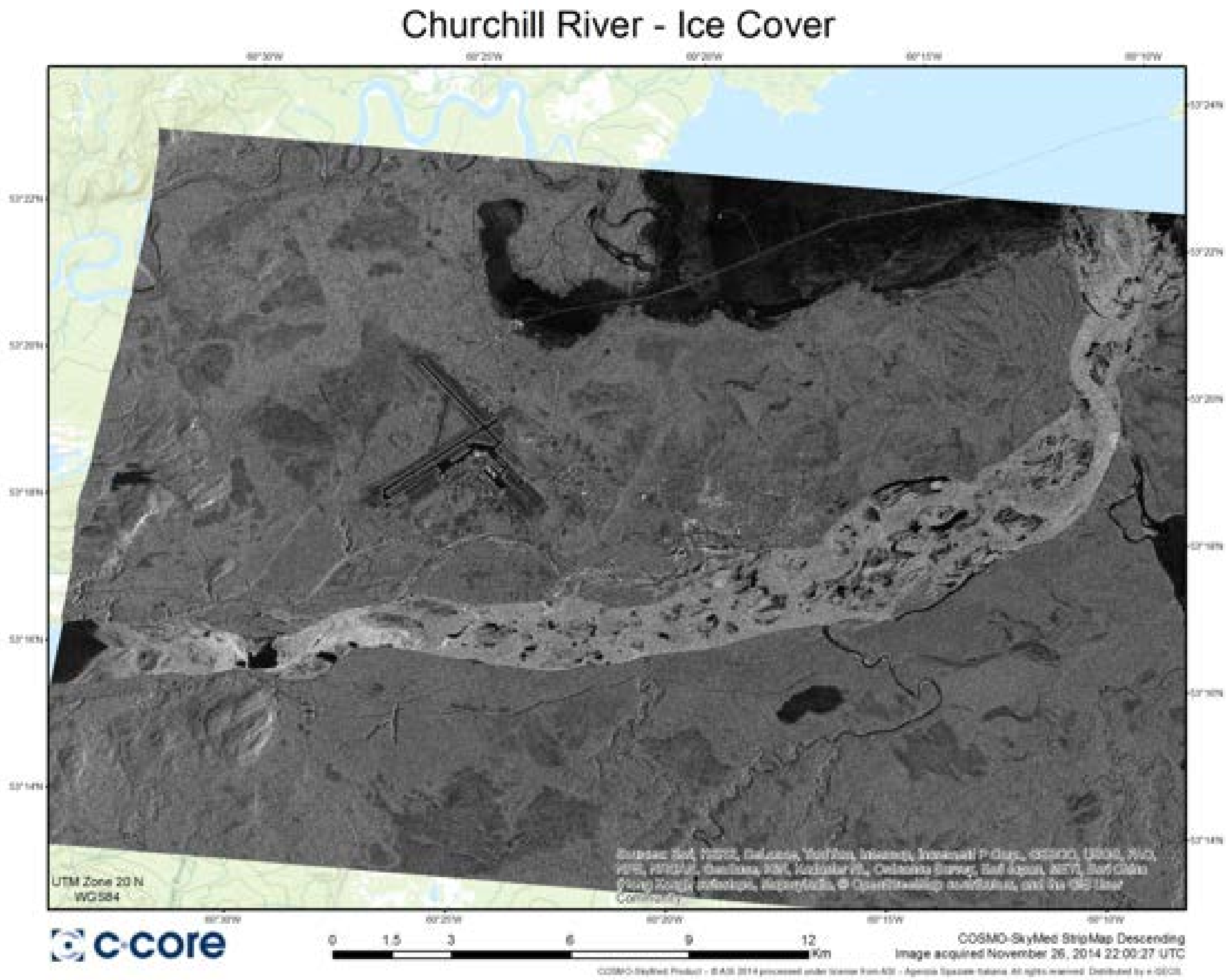

Churchill River - Ice Classification
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0 2.25 4.5 9 13.5 18 Km
COSMO-SkyMed StripMap Ascending
Image acquired November 25, 2014 09:37:25 UTC

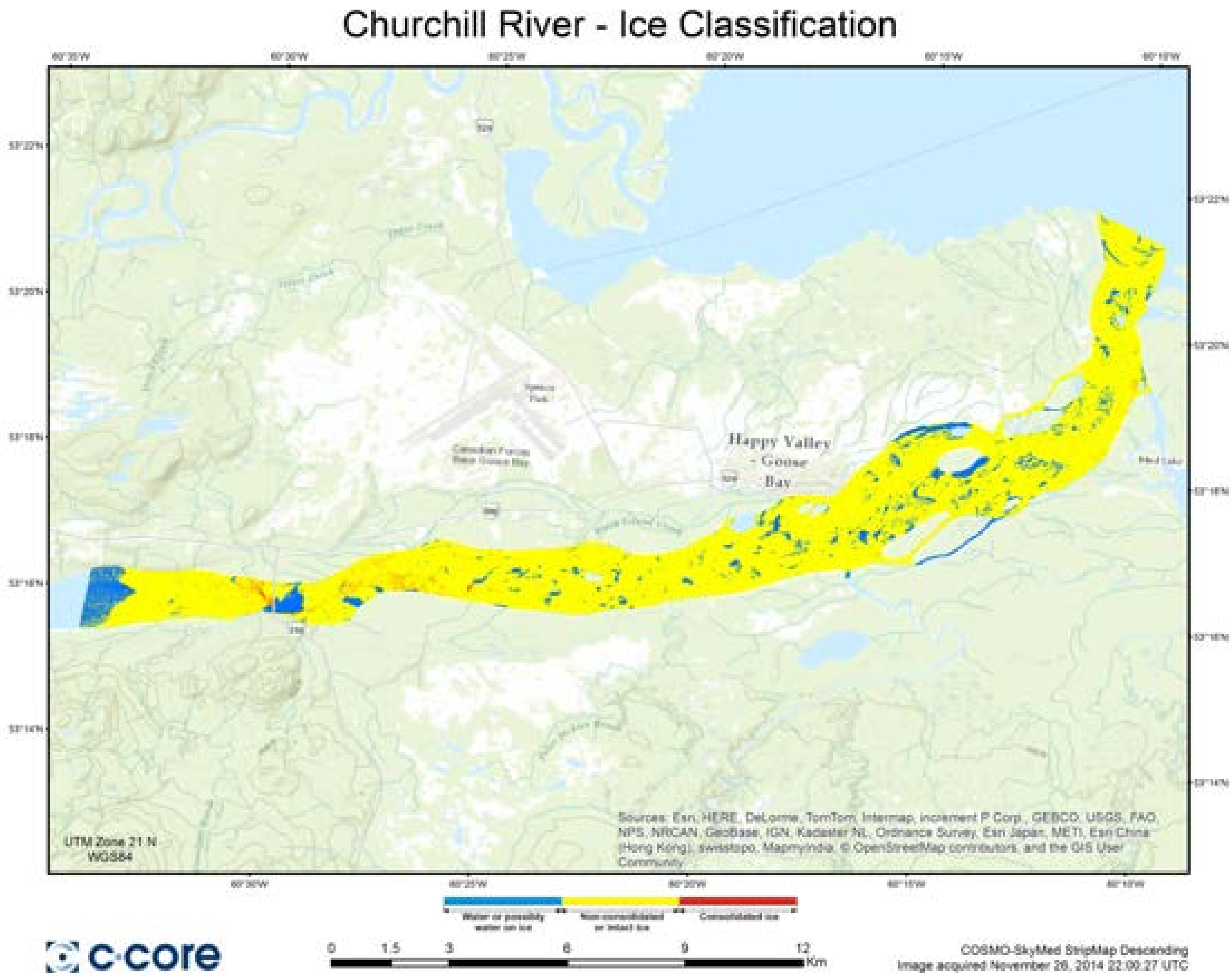

Churchill River - Ice Cover
UTM Zone 20 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
c-core
0 2 4 8 12 16
Km
COSMO-SkyMed StripMap Ascending
Image acquired November 26, 2014 09:37:24 UTC

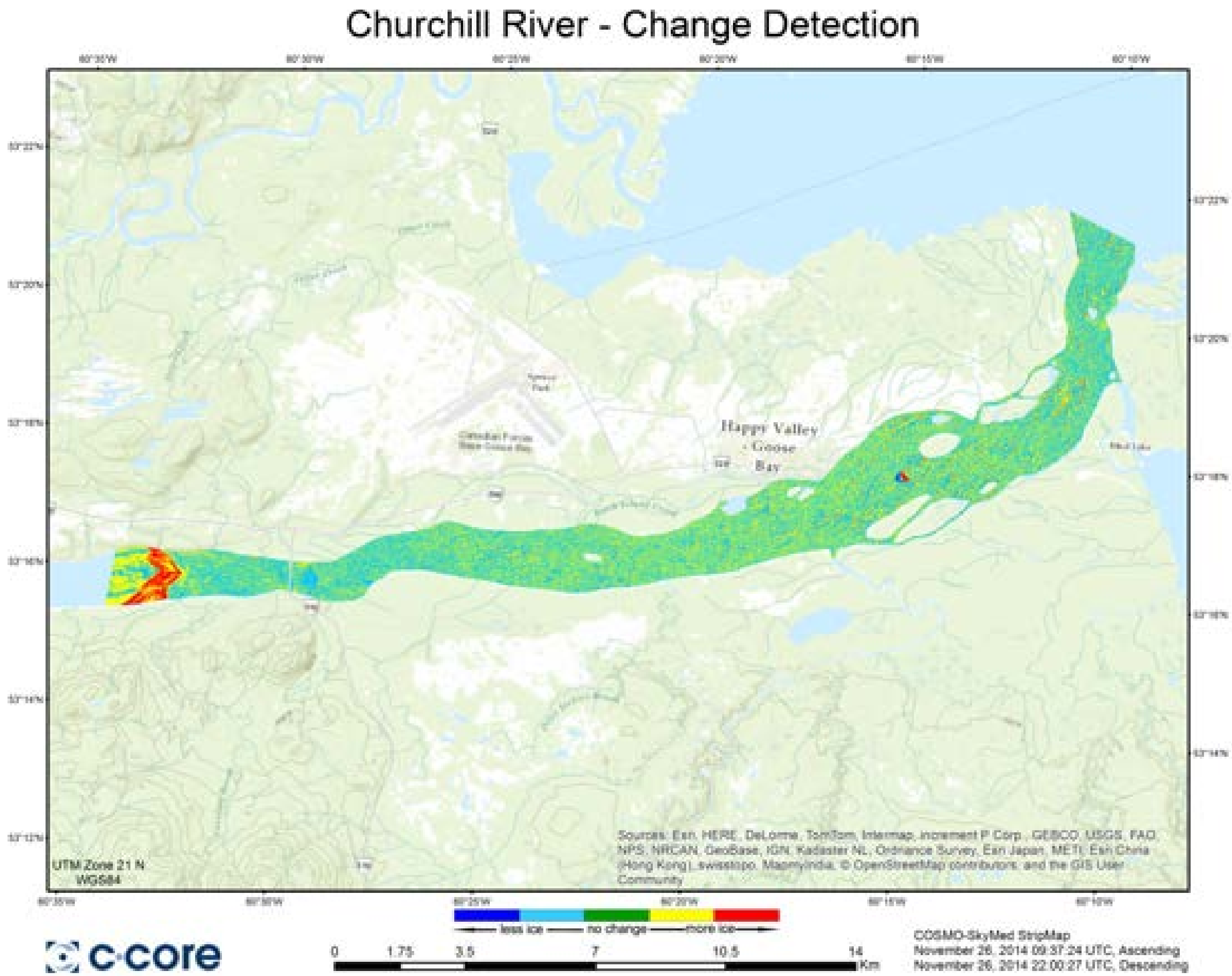

Churchill River - Ice Classification
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0 2.25 4.5 9 13.5 18 Km
COSMO-SkyMed StripMap Ascending
Image acquired November 26, 2014 09:37:24 UTC

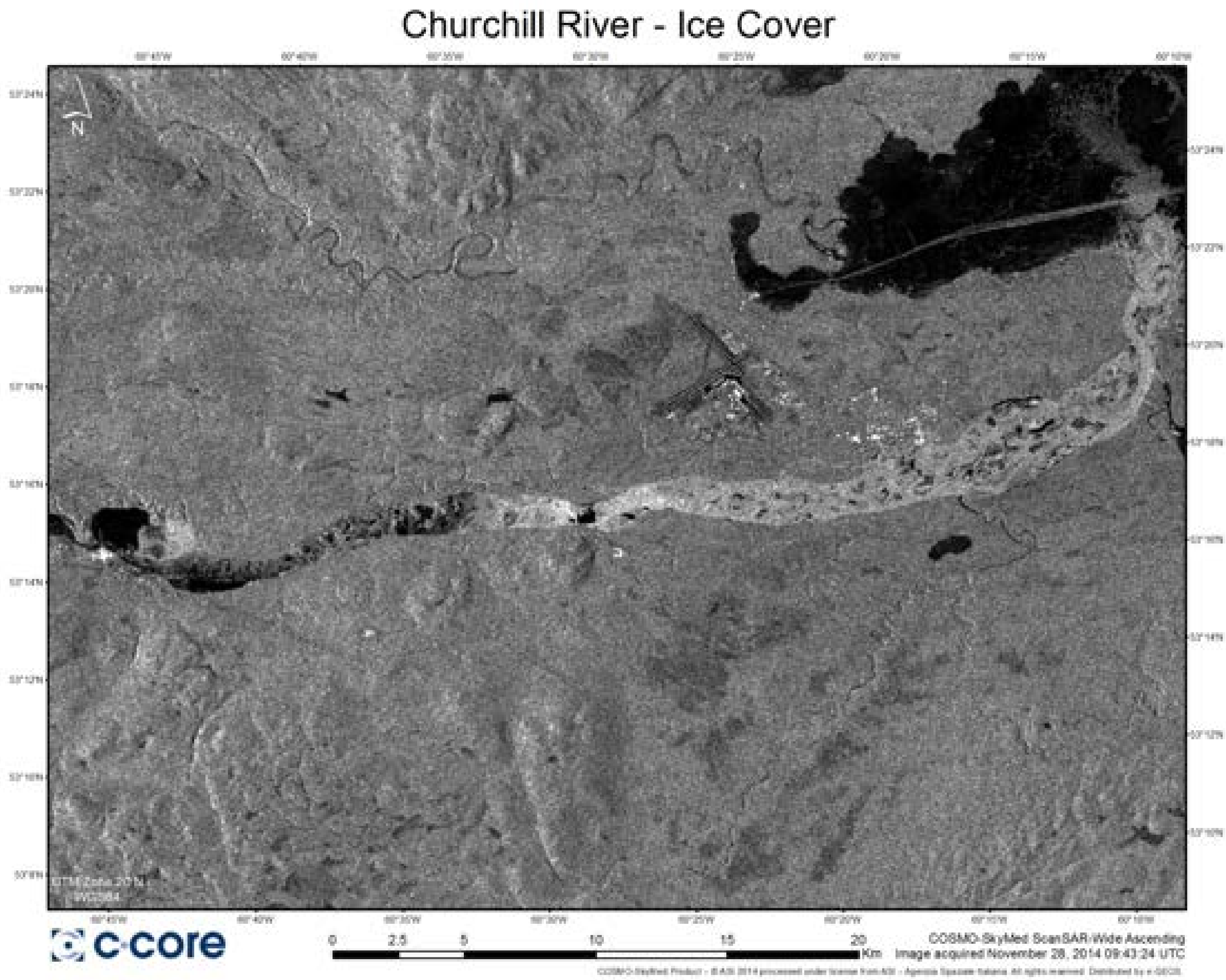
Churchill River - Change Detection

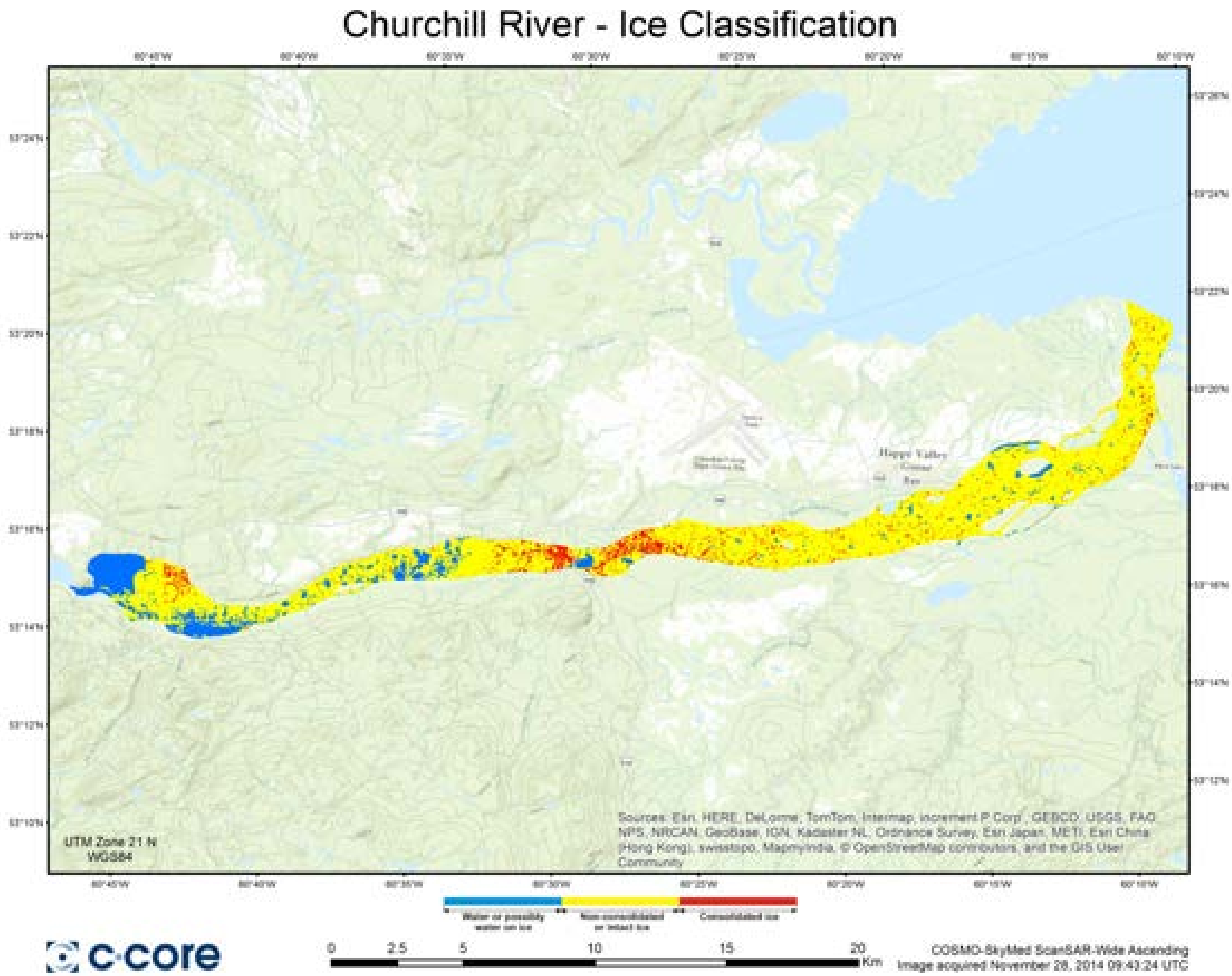



Churchill River - Ice Cover
UTM Zone 20 N
WGS84
0 1.5 3 6 9 12 Km
COSMO-SkyMed StripMap Descending
Image acquired November 26, 2014 22:00:27 UTC

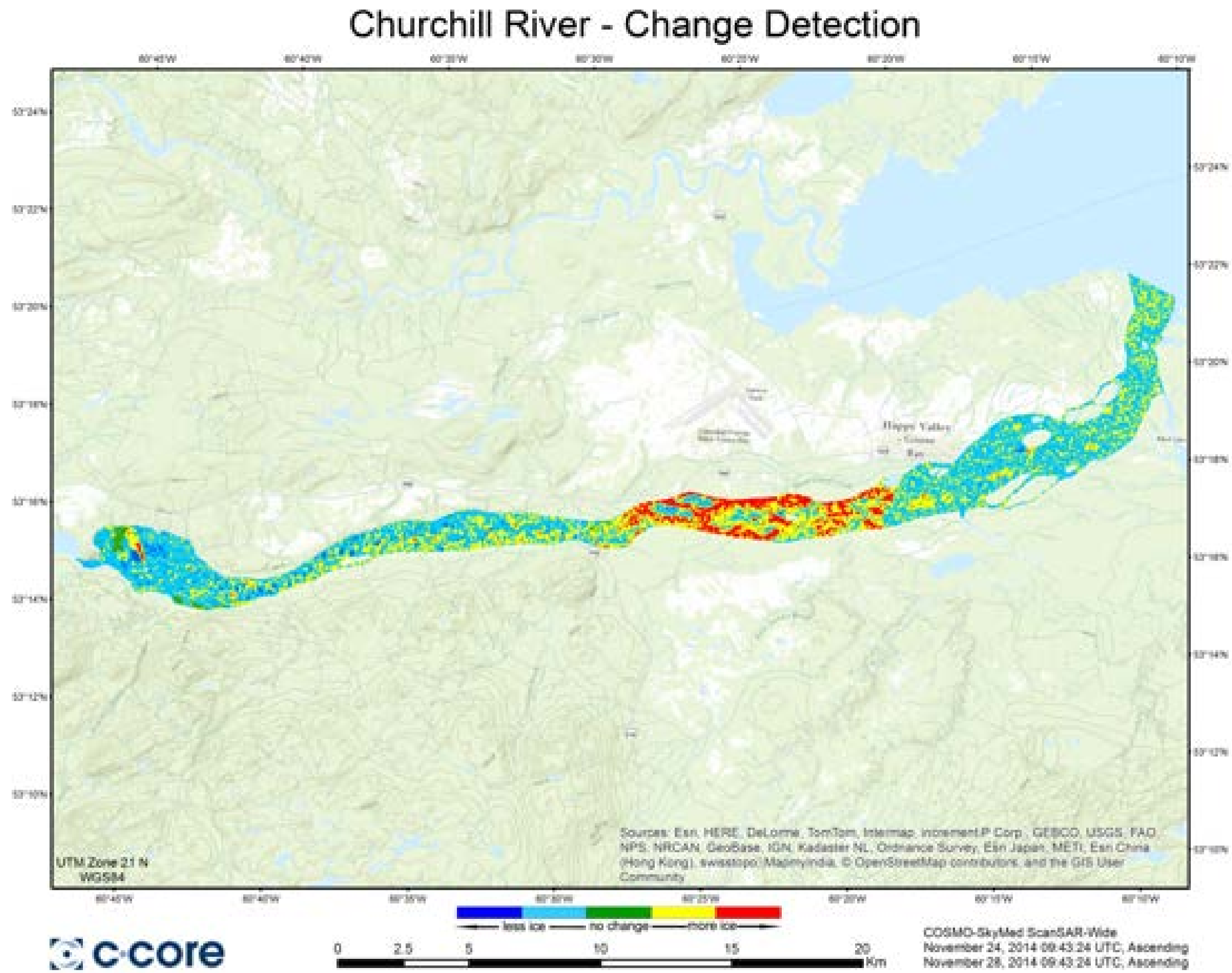

Churchill River - Ice Classification
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 1.5 3 6 9 12 Km
COSMO-SkyMed StripMap Descending
Image acquired November 26, 2014 22:00:27 UTC

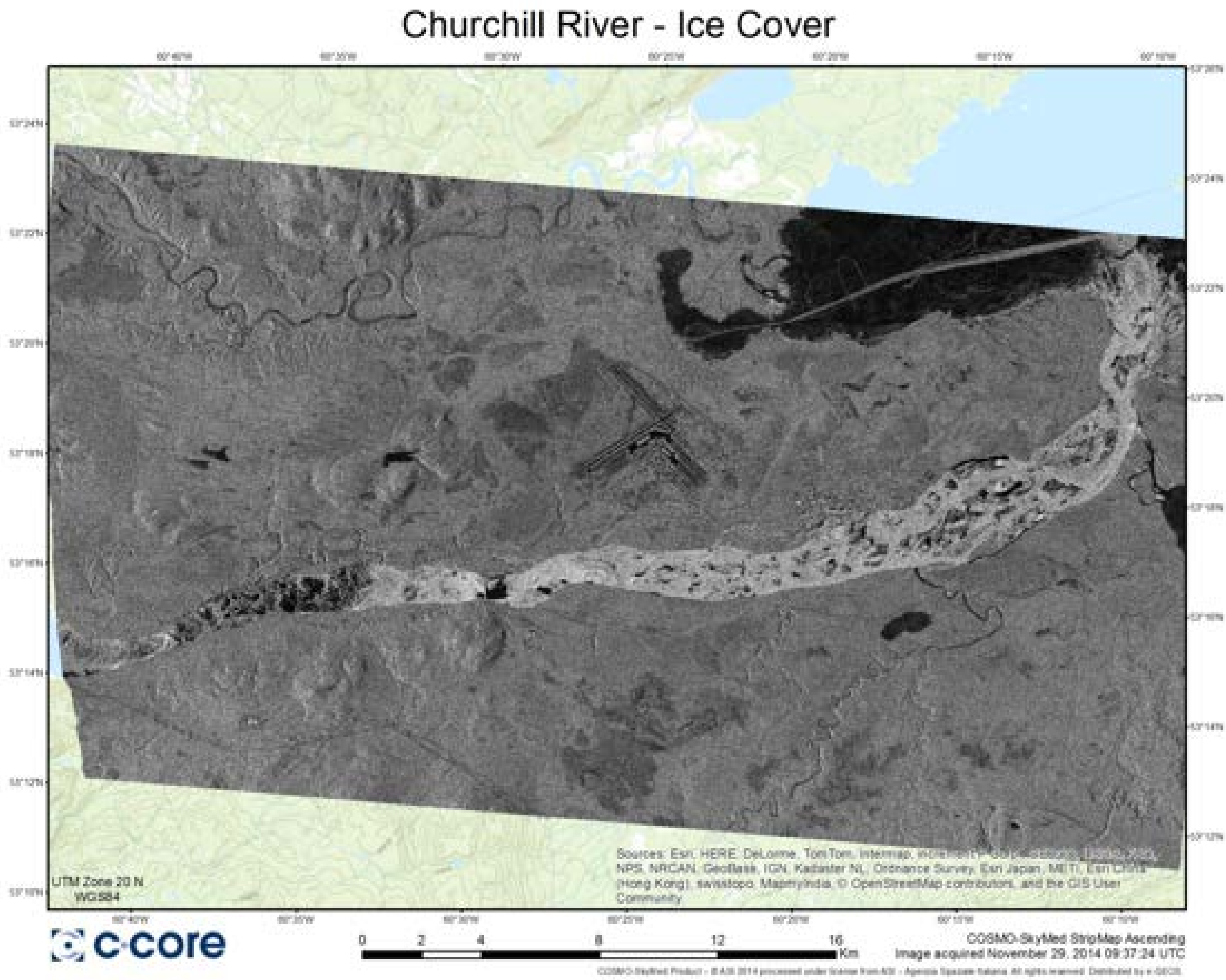

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
1.75
3.5
7
10.5
14
Km
COSMO-SkyMed StripMap
November 26, 2014 09:37:24 UTC, Ascending
November 26, 2014 22:00:27 UTC, Descending

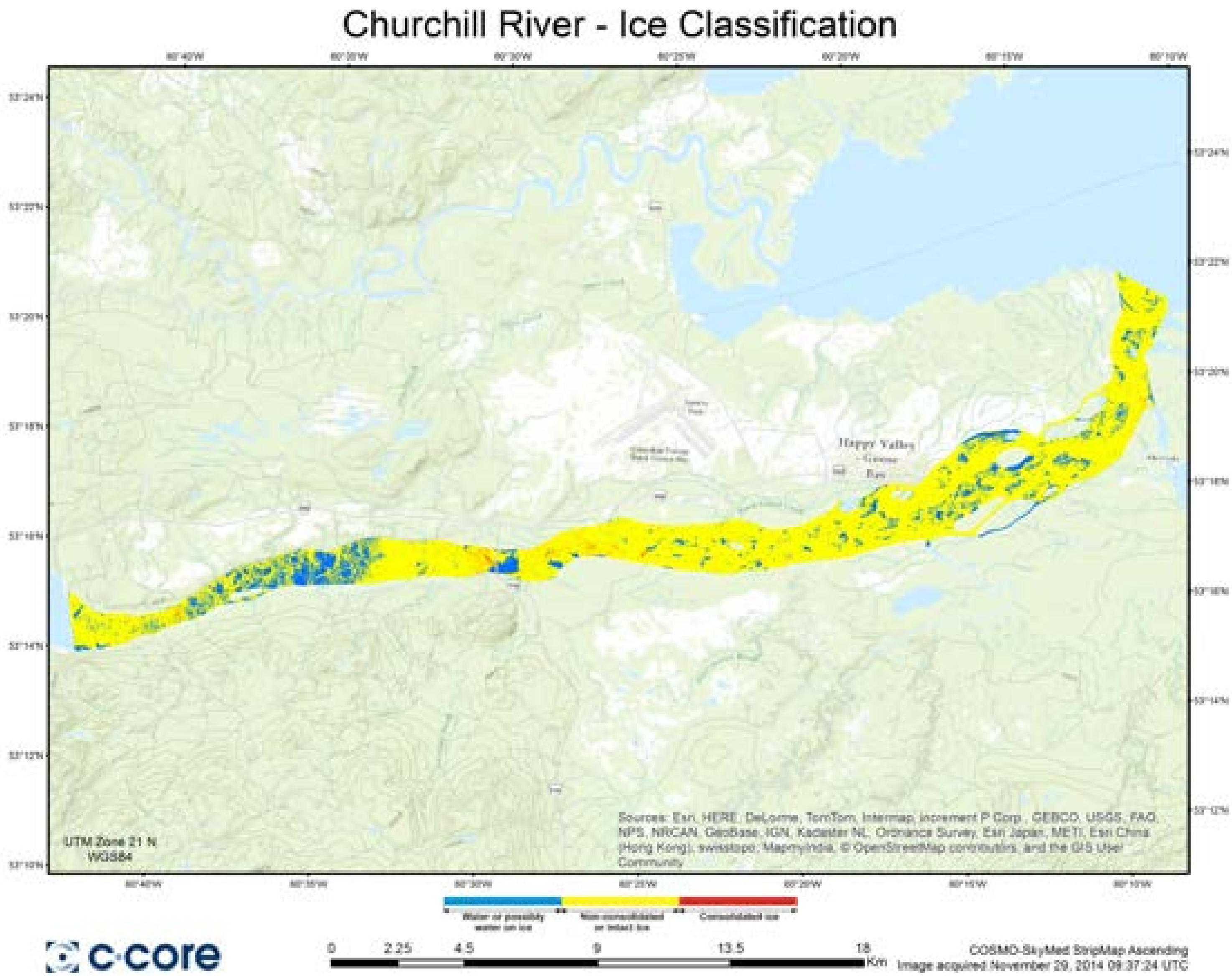

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired November 28, 2014 09:43:24 UTC
COSMO-SkyMed Product - © ASI 2014 processed under license from ASI - Agenzia Spaziale Italiana. All rights reserved. Distributed by e-GEOS.



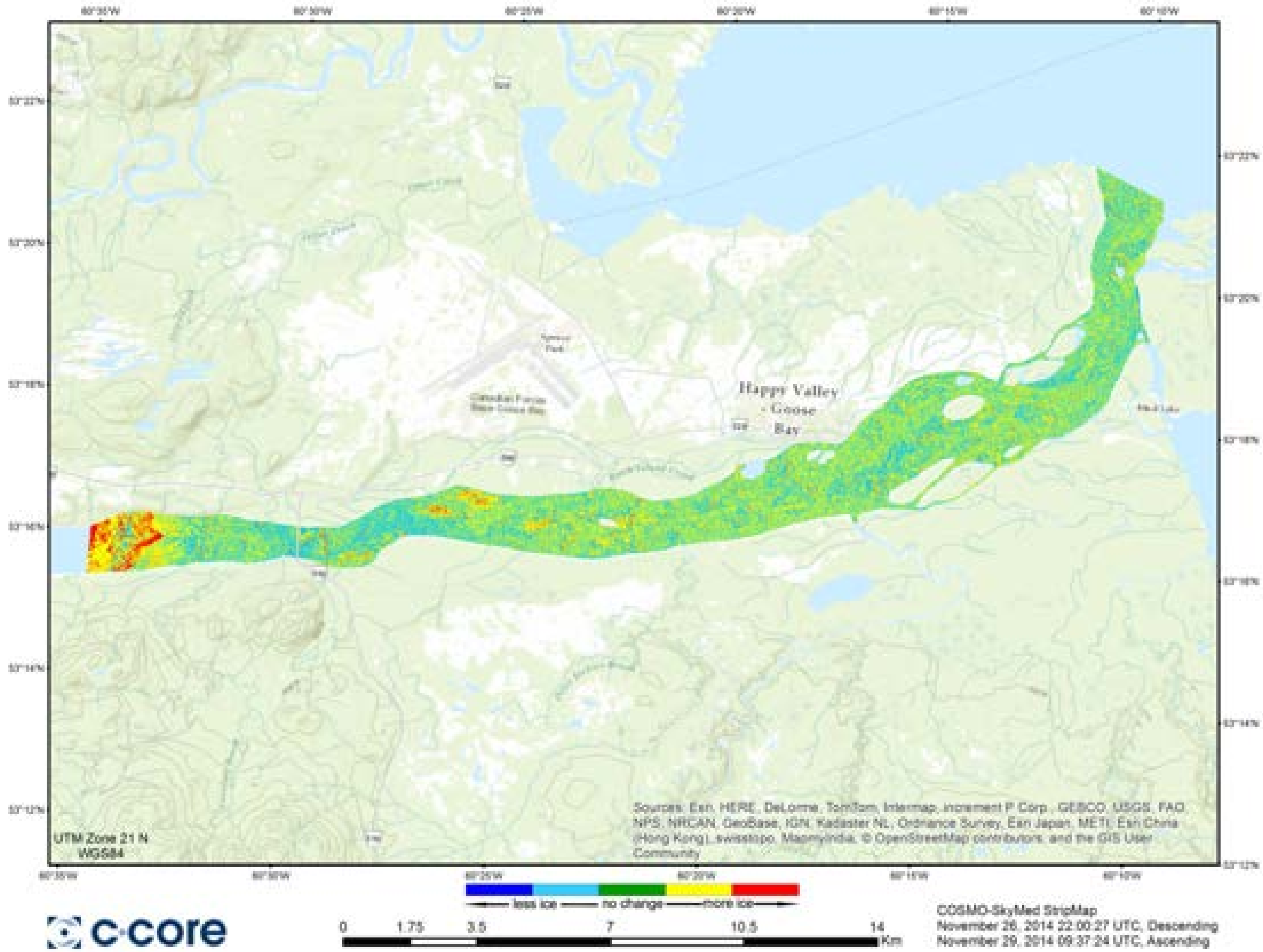
Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired November 28, 2014 09:43:24 UTC

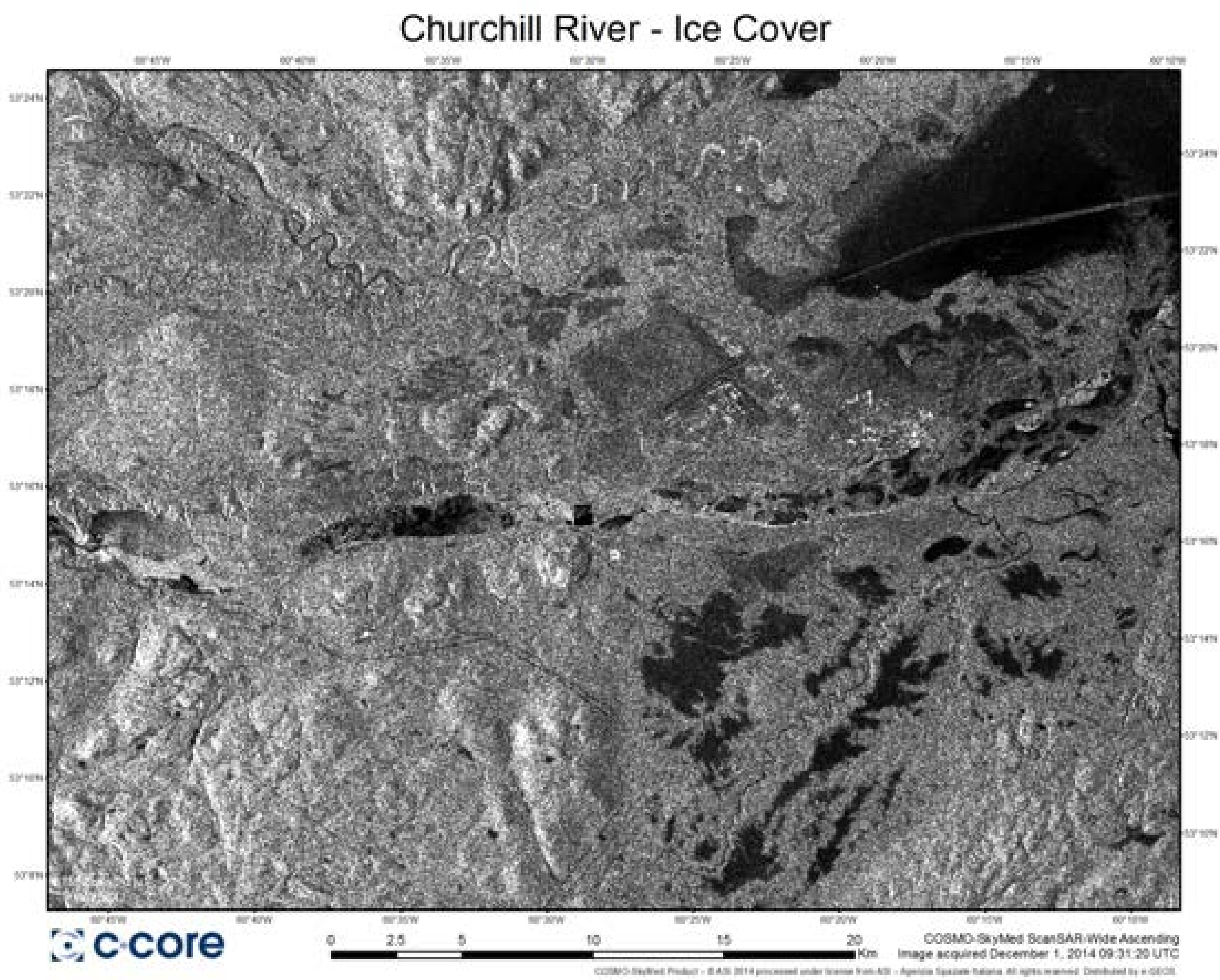

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
November 24, 2014 09:43:24 UTC, Ascending
November 28, 2014 09:43:24 UTC, Ascending

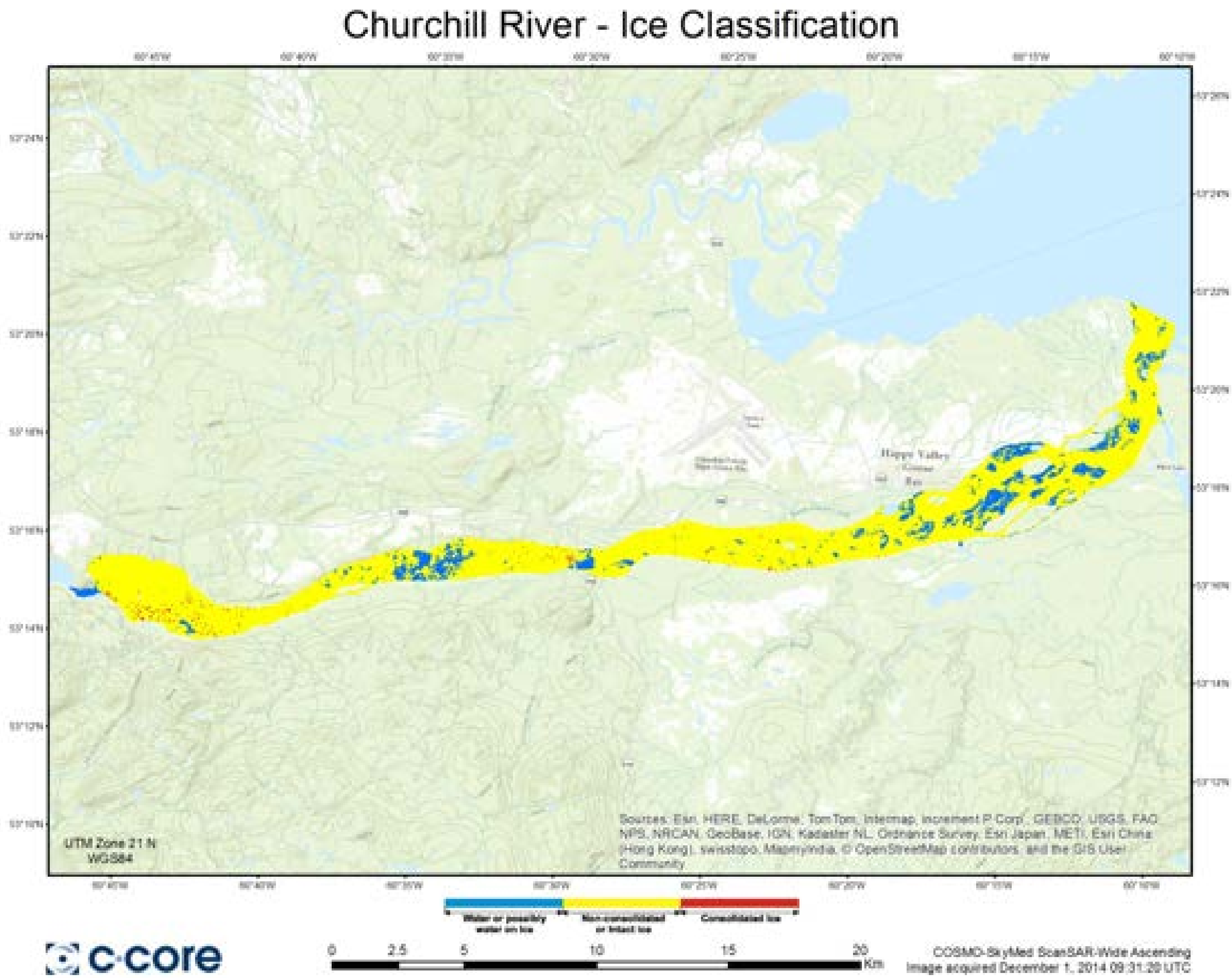

Churchill River - Ice Cover
UTM Zone 20 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap,
NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China
(Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User
Community
0 2 4 8 12 16
Km
COSMO-SkyMed StripMap Ascending
Image acquired November 29, 2014 09:37:24 UTC

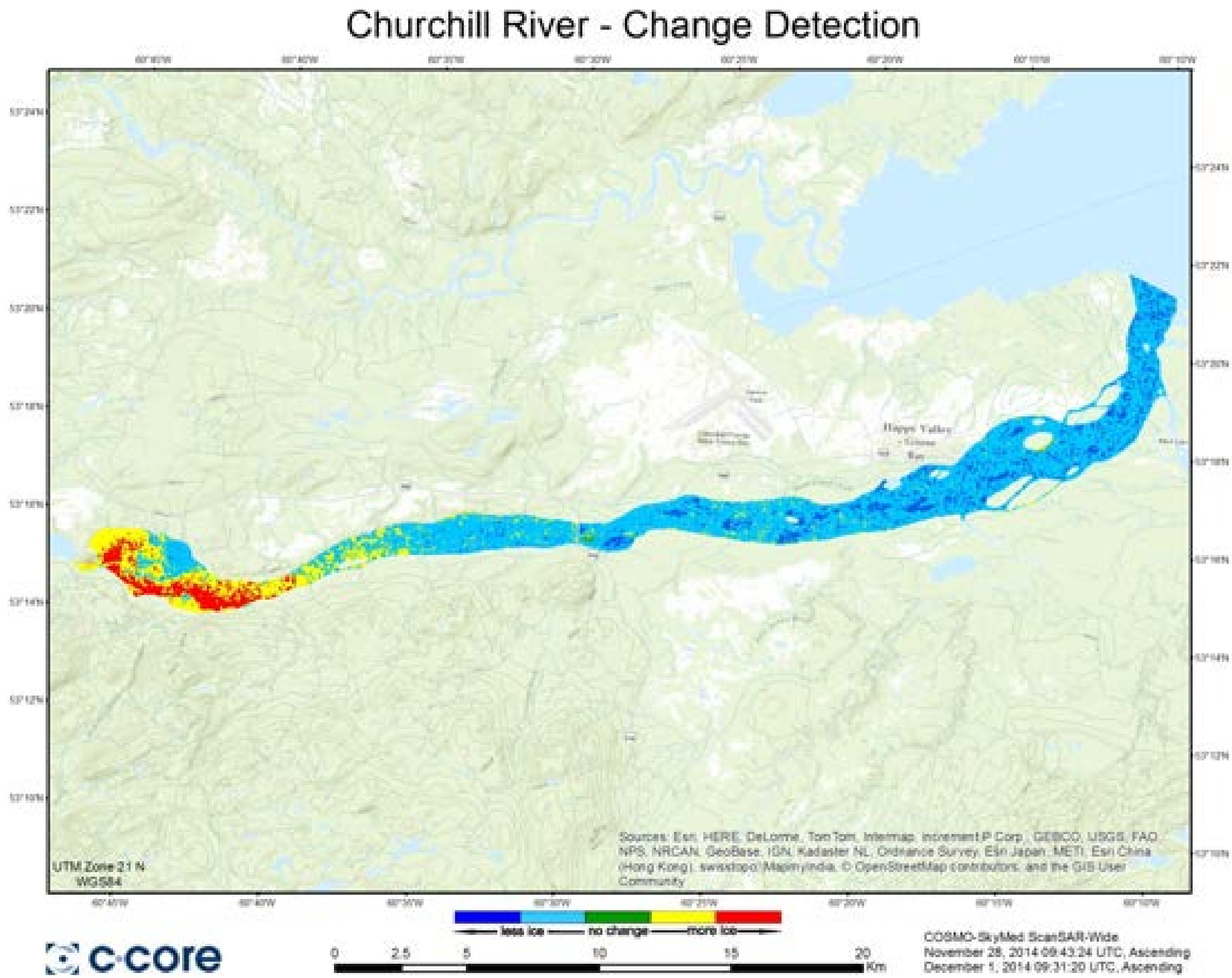

Churchill River - Ice Classification
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0 2.25 4.5 9 13.5 18 Km
COSMO-SkyMed StripMap Ascending
Image acquired November 29, 2014 09:37:24 UTC

Churchill River - Change Detection

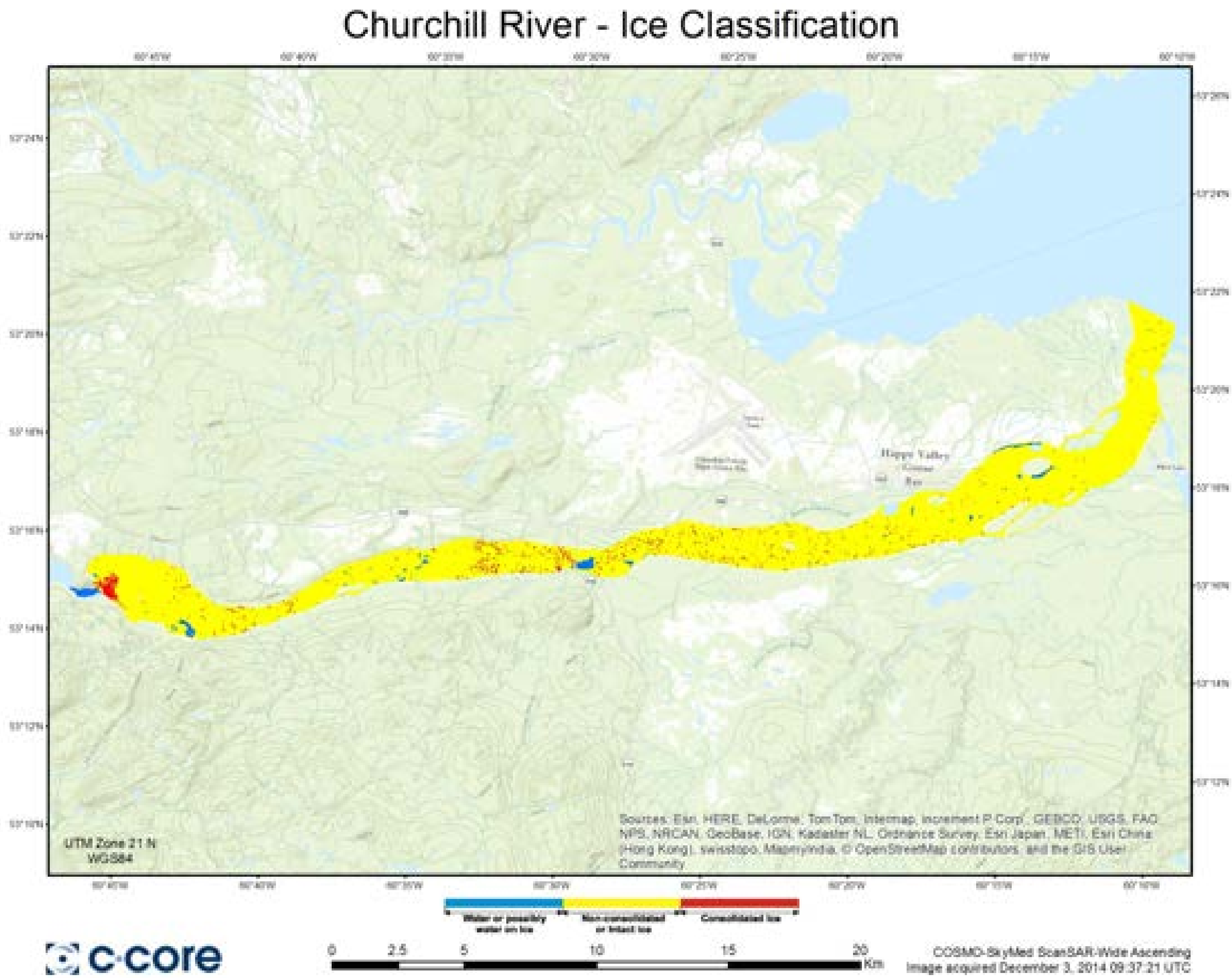


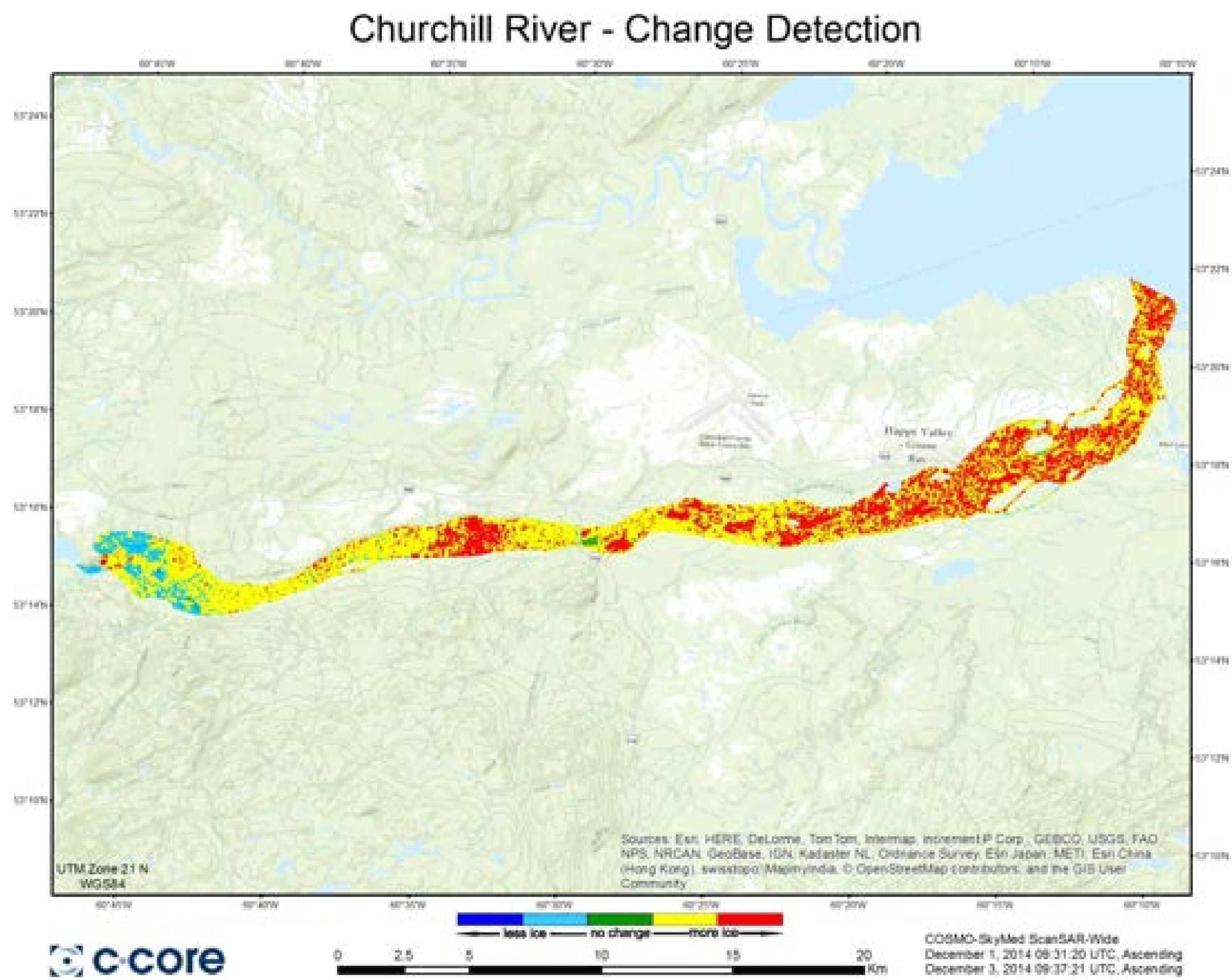

Churchill River - Ice Cover
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 1, 2014 09:31:20 UTC


Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 1, 2014 09:31:20 UTC
c-core


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
November 28, 2014 09:43:24 UTC, Ascending
December 1, 2014 09:31:20 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 3, 2014 09:37:21 UTC

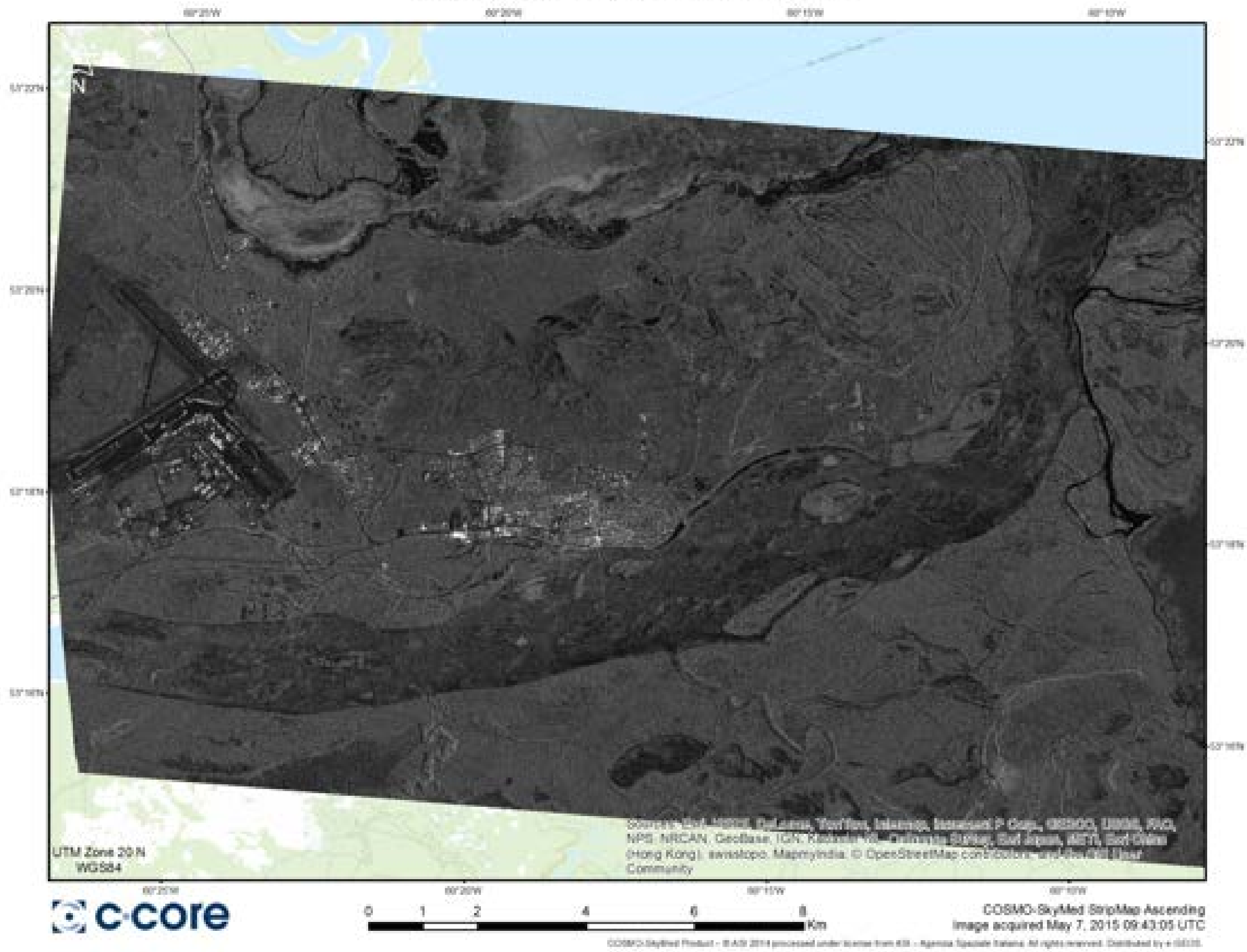

Churchill River - Ice Classification
Happy Valley
Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 3, 2014 09:37:21 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
December 1, 2014 09:31:20 UTC, Ascending
December 3, 2014 09:37:21 UTC, Ascending

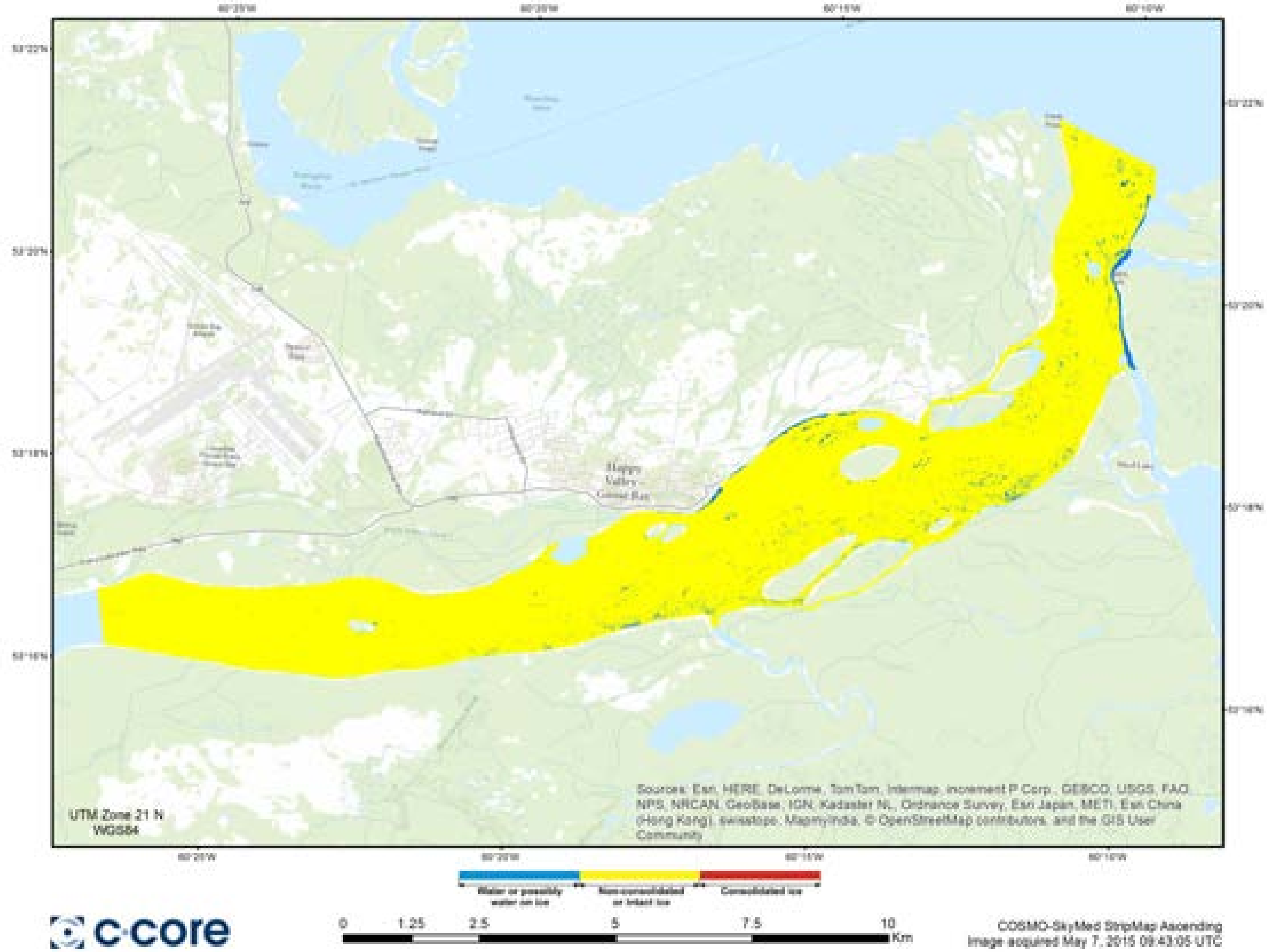
APPENDIX C

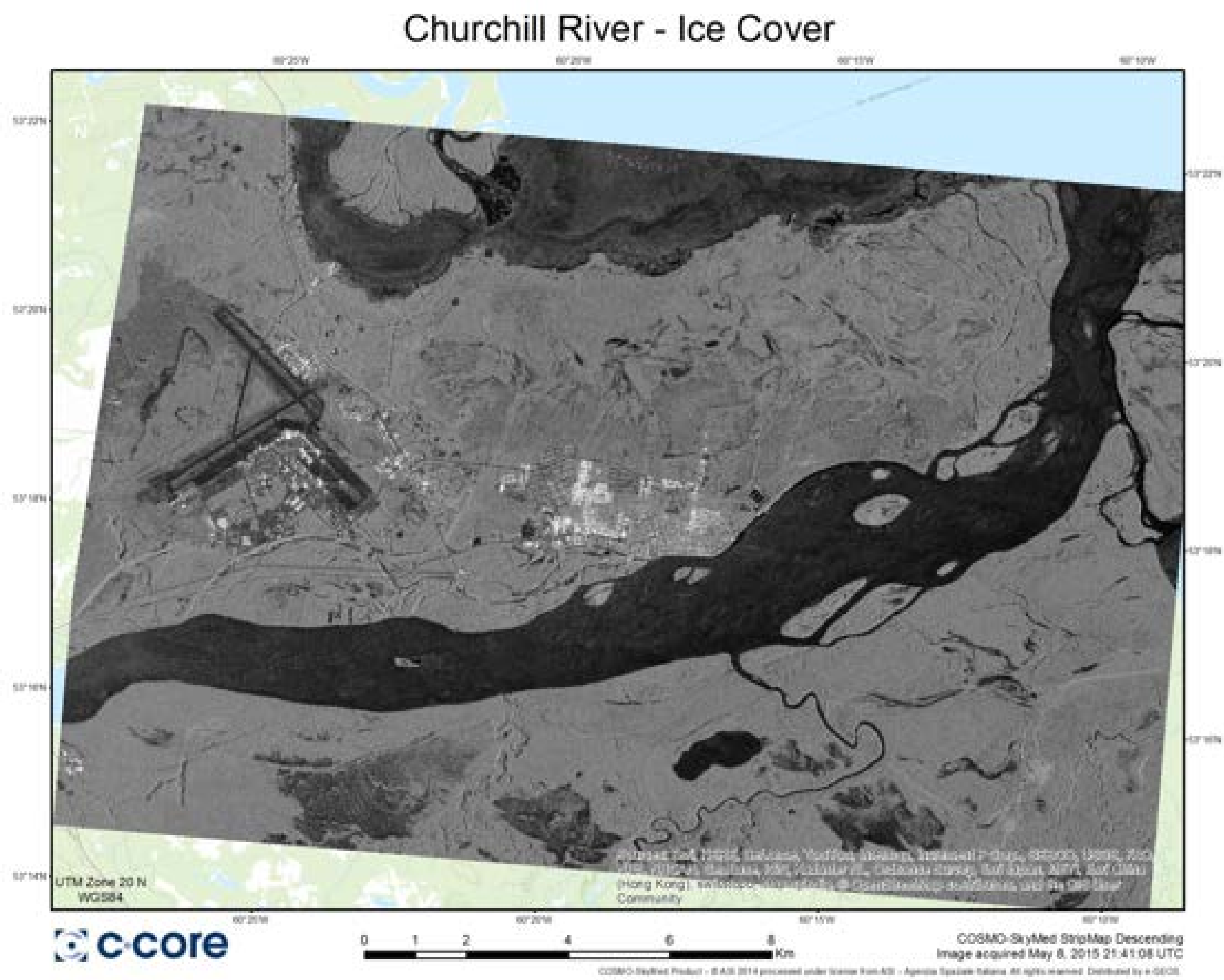
Mud Lake Break-up Satellite Imagery

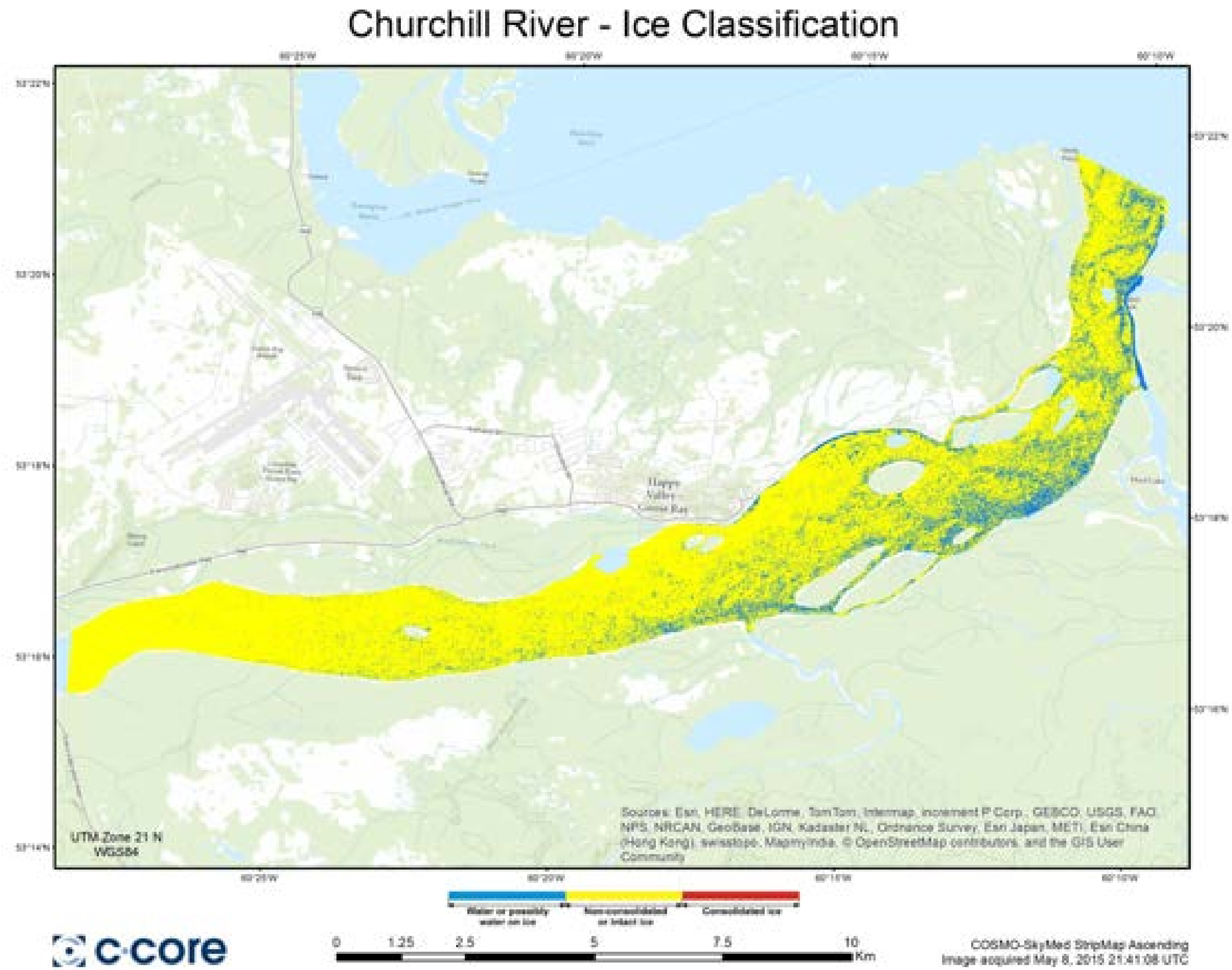
Churchill River - Ice Cover

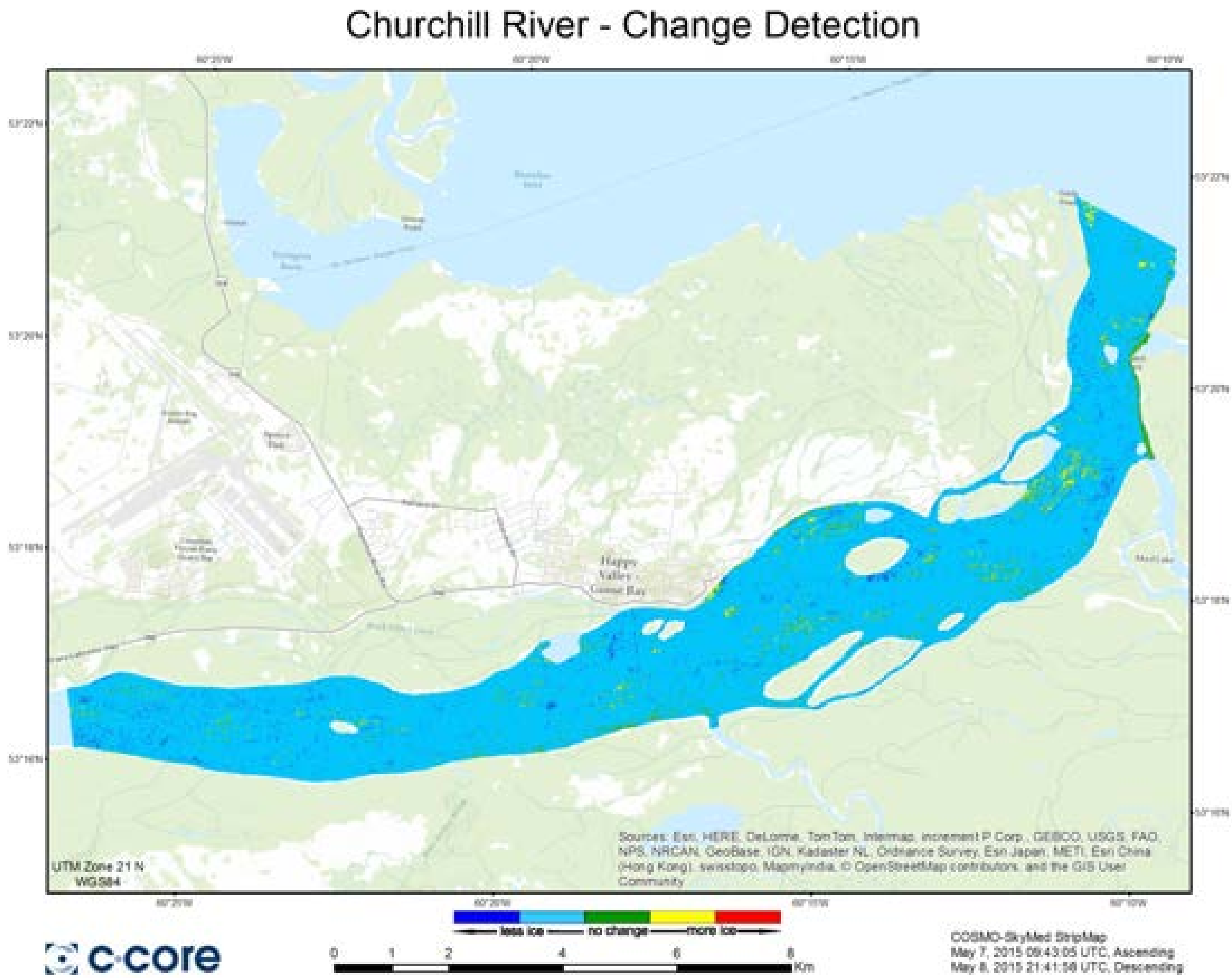


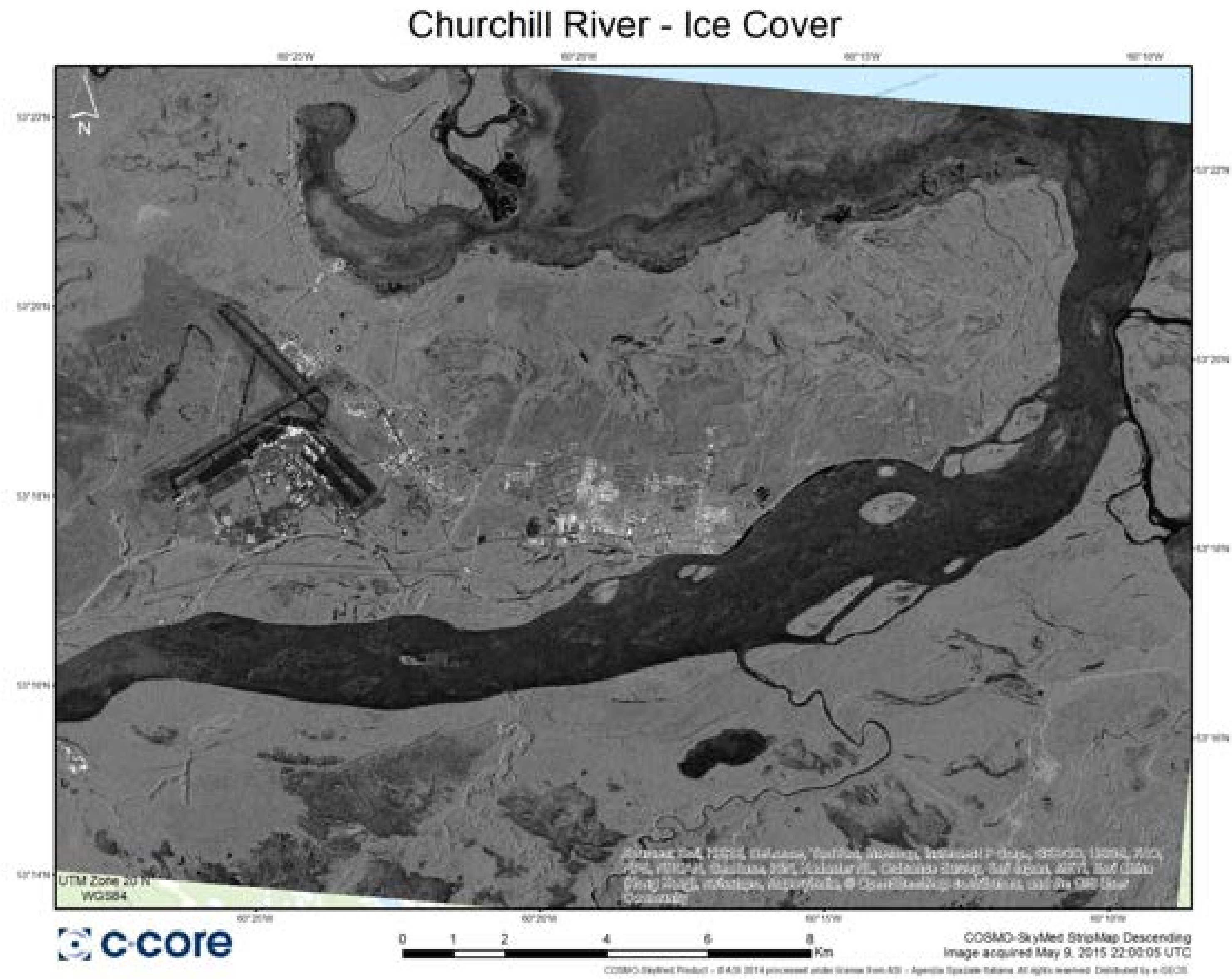
Churchill River - Ice Classification

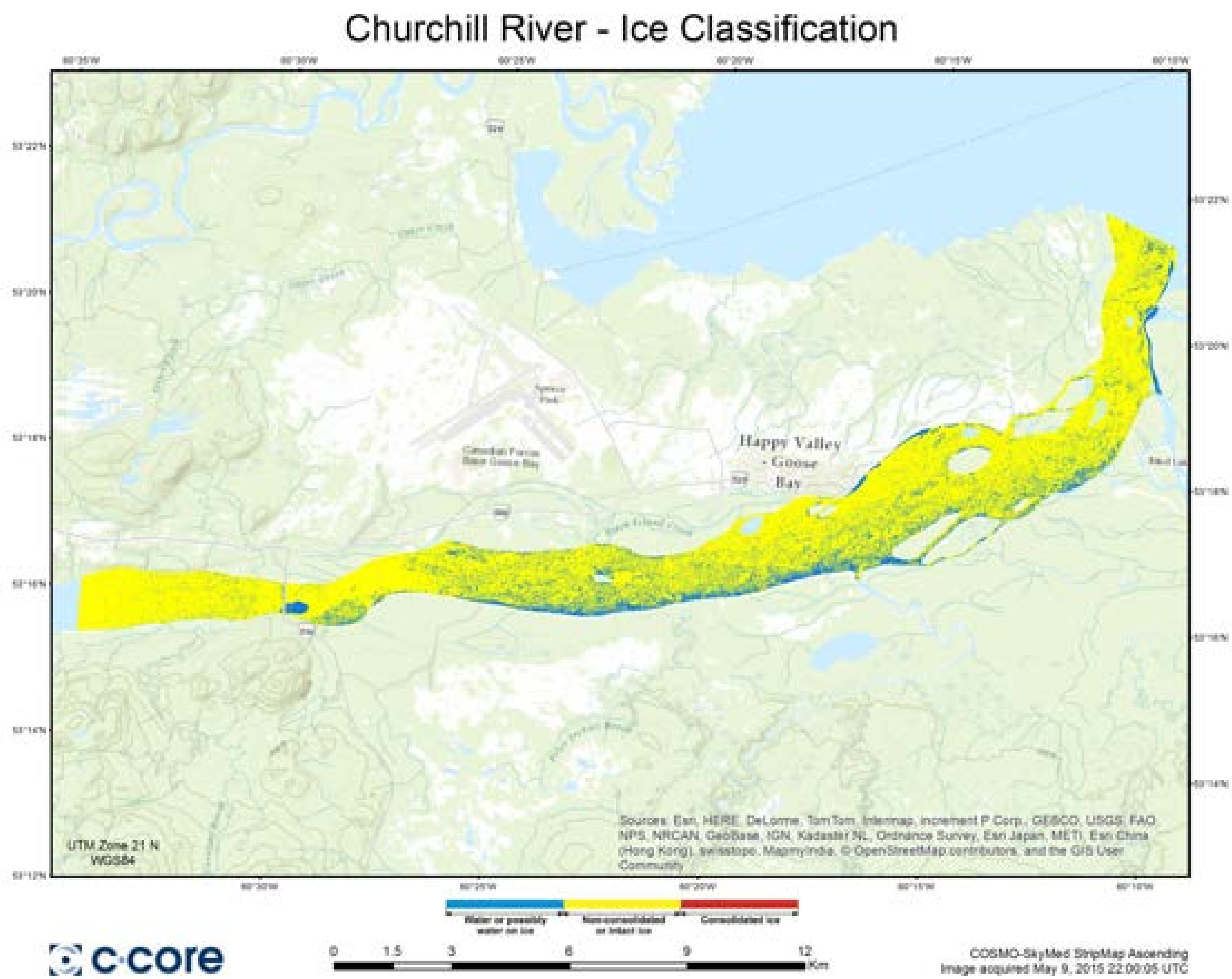


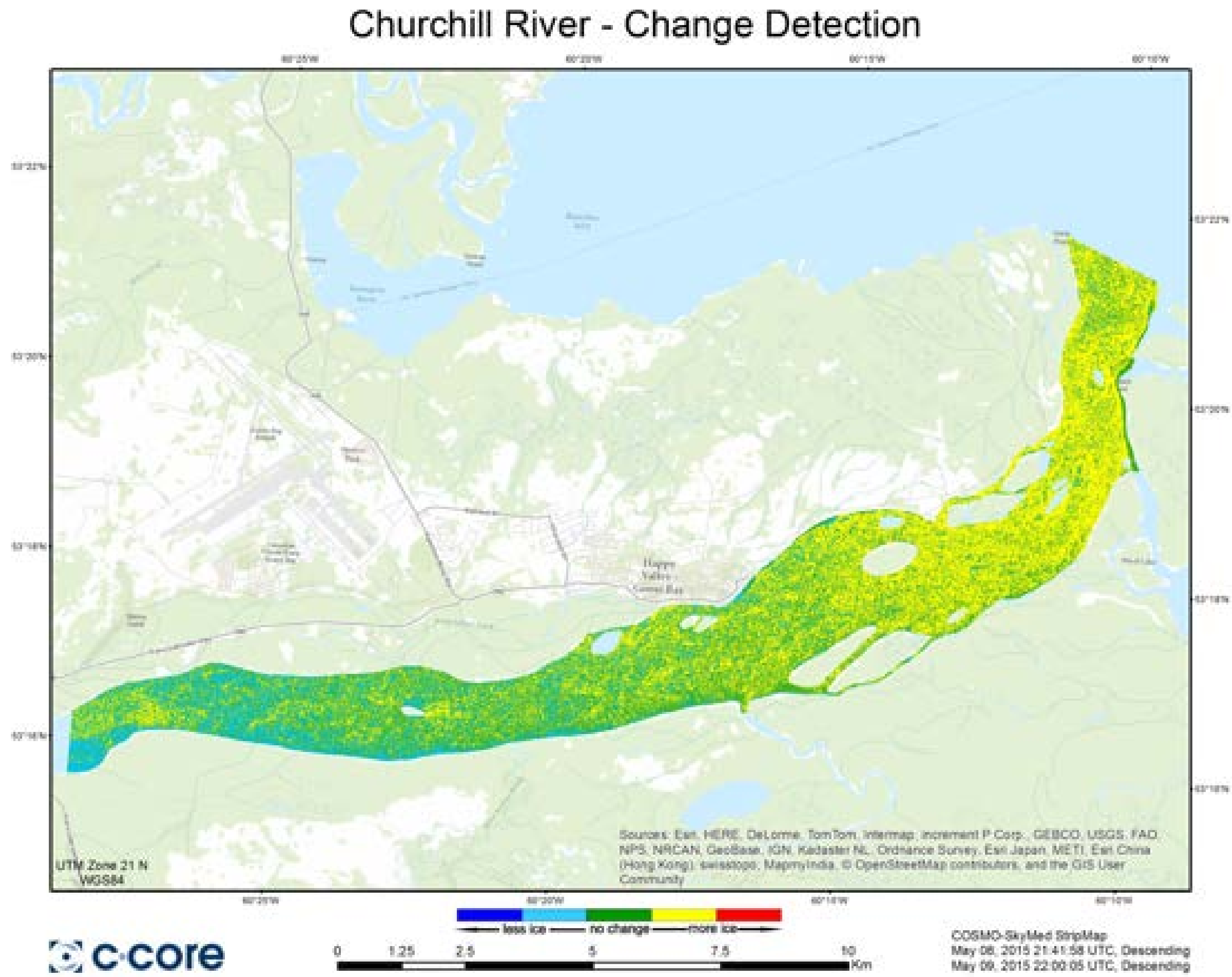

Churchill River - Ice Cover
UTM Zone 20 N
WGS84
c-core
0 1 2 4 6 8 Km
COSMO-SkyMed StripMap Descending
Image acquired May 8, 2015 21:41:08 UTC


Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or Intact ice
Consolidated ice
0 1.25 2.5 5 7.5 10 Km
COSMO-SkyMed StripMap Ascending
Image acquired May 8, 2015 21:41:08 UTC

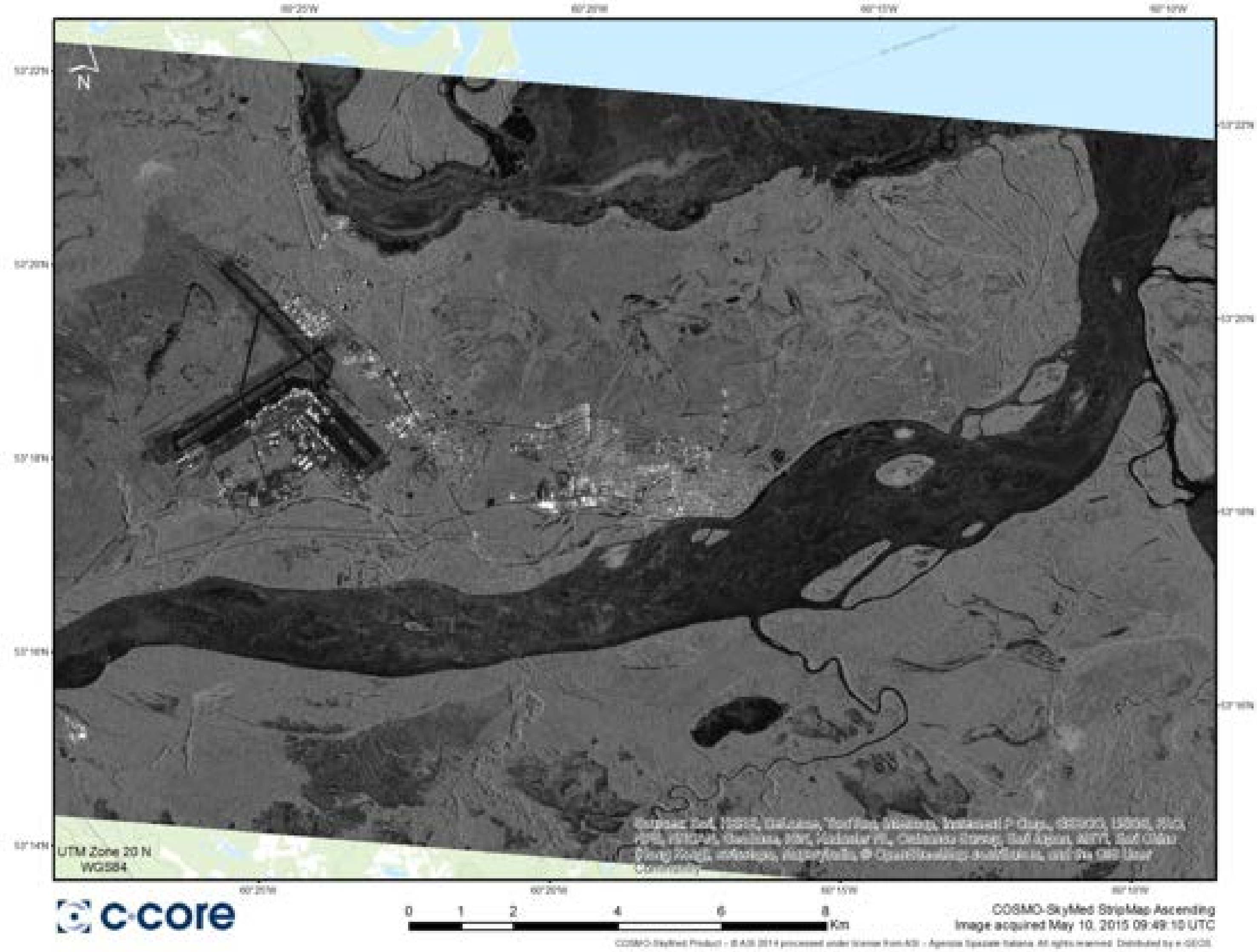

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
1
2
4
6
8
Km
COSMO-SkyMed StripMap
May 7, 2015 09:43:05 UTC, Ascending
May 8, 2015 21:41:58 UTC, Descending

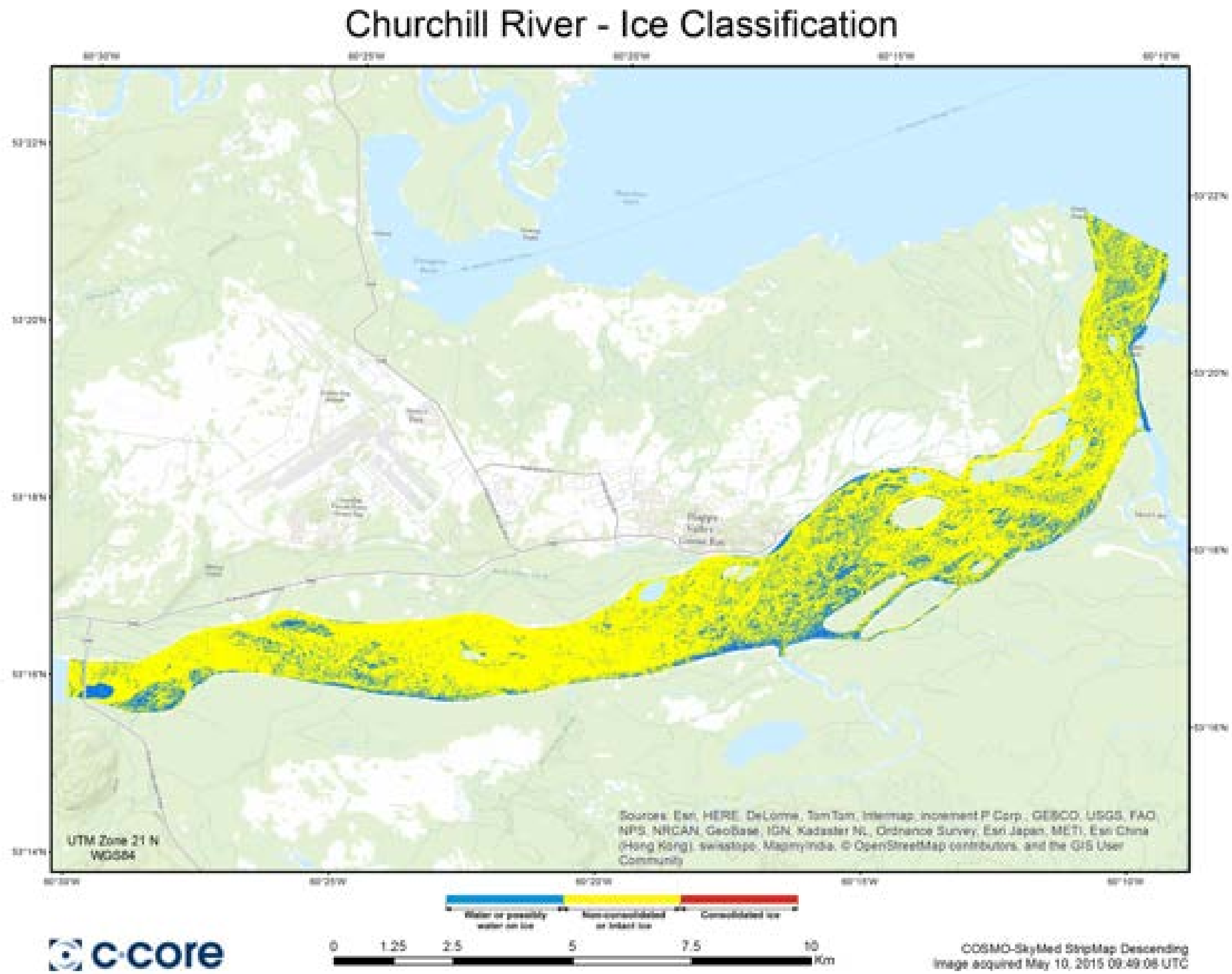

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0
1
2
4
6
8
Km
COSMO-SkyMed StripMap Descending
Image acquired May 9, 2015 22:00:05 UTC

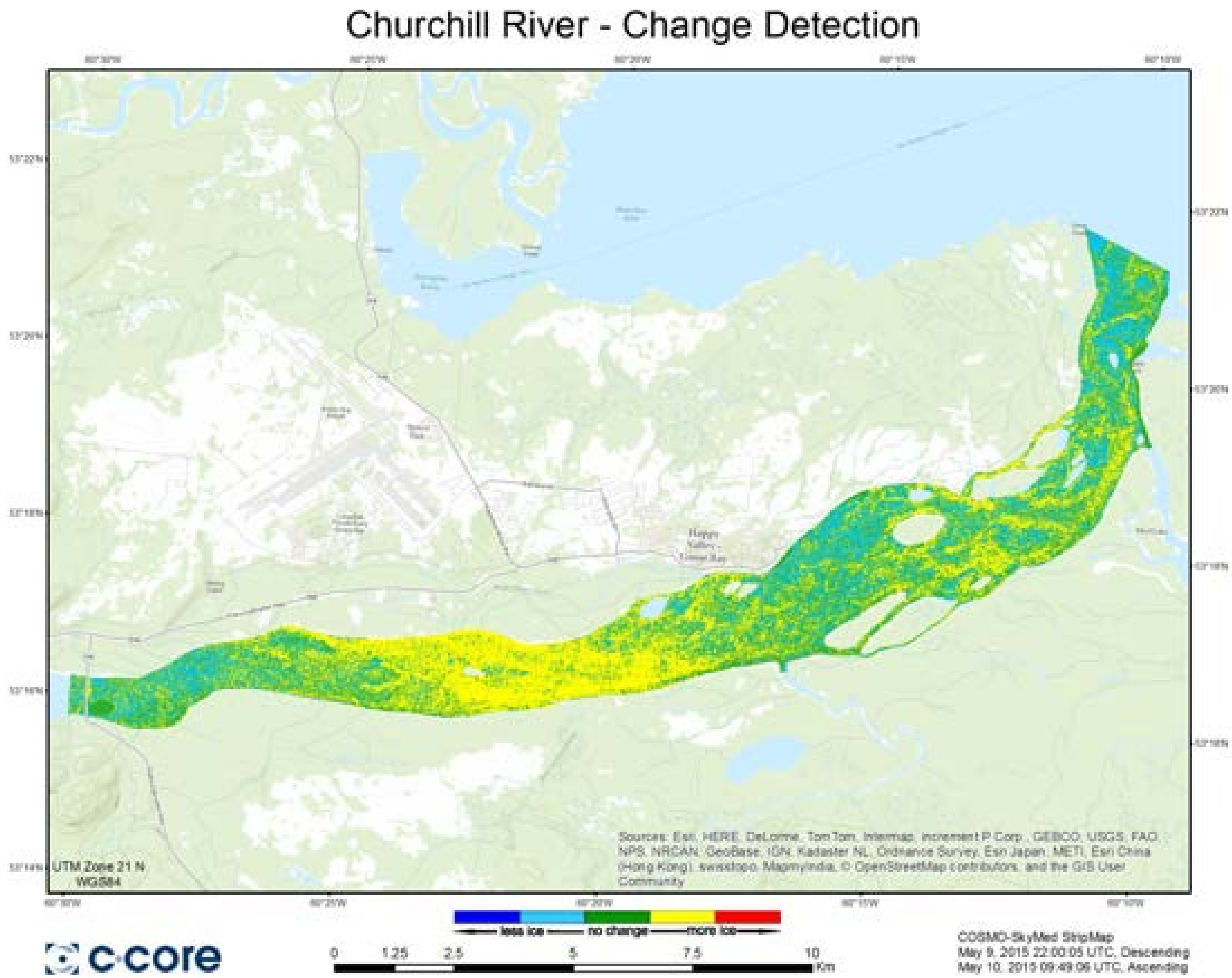

Churchill River - Ice Classification
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or brash ice
Consolidated ice
0 1.5 3 6 9 12 Km
COSMO-SkyMed StripMap Ascending
Image acquired May 9, 2015 22:00:05 UTC

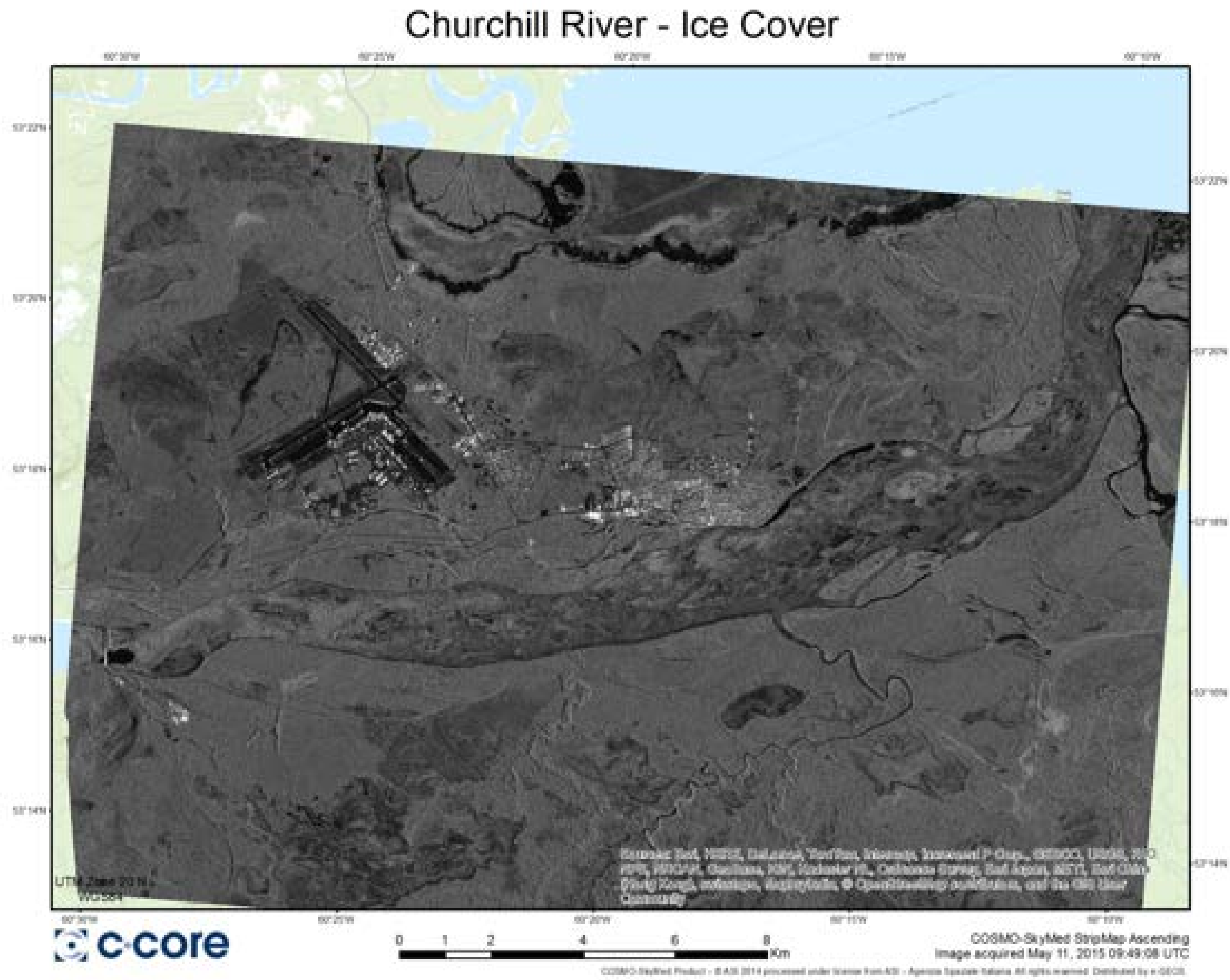

Churchill River - Change Detection
Happy Valley-Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
less ice
no change
more ice
0
1.25
2.5
5
7.5
10
Km
COSMO-SkyMed StripMap
May 08, 2015 21:41:58 UTC, Descending
May 09, 2015 22:00:05 UTC, Descending

Churchill River - Ice Cover

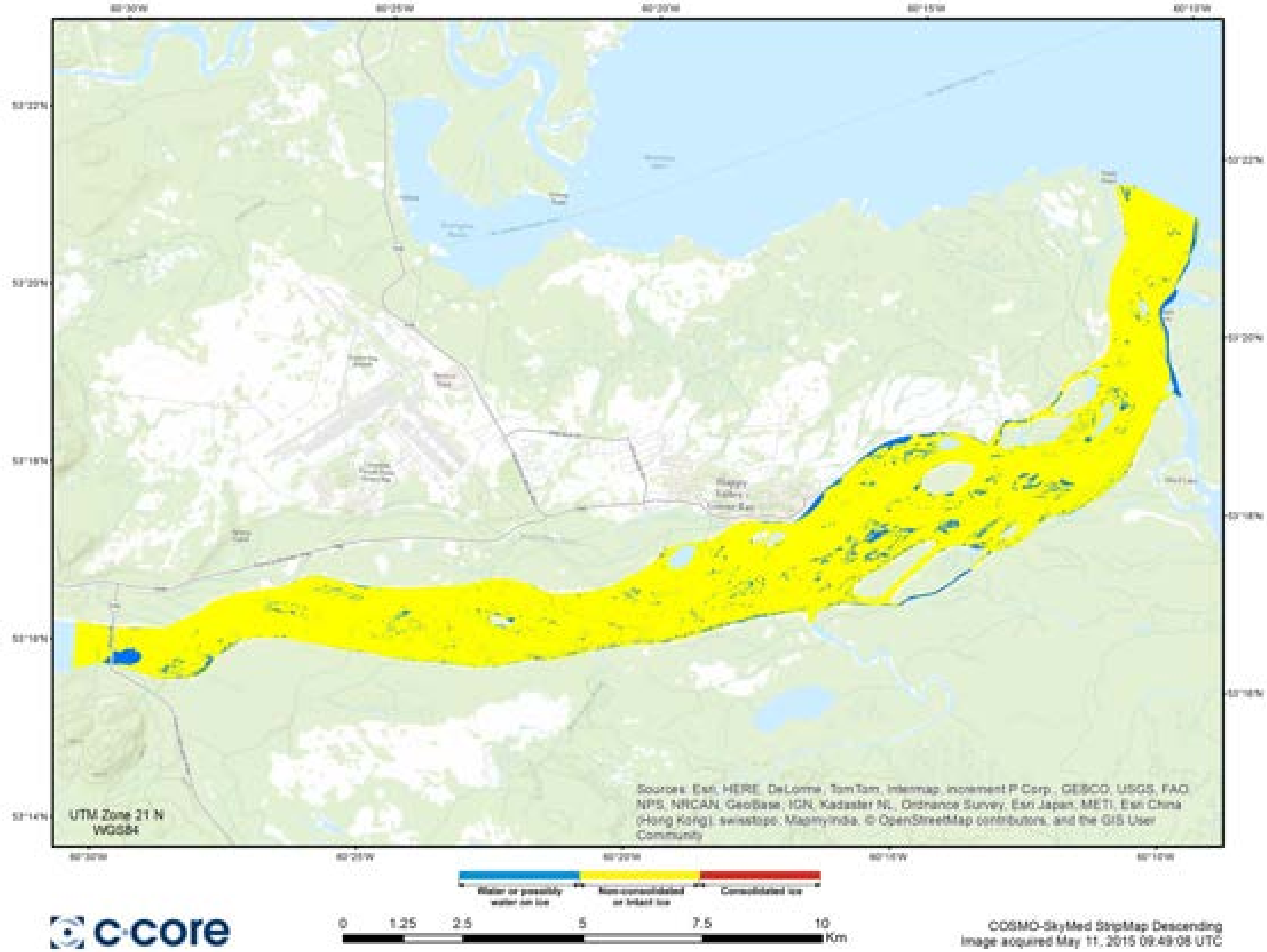


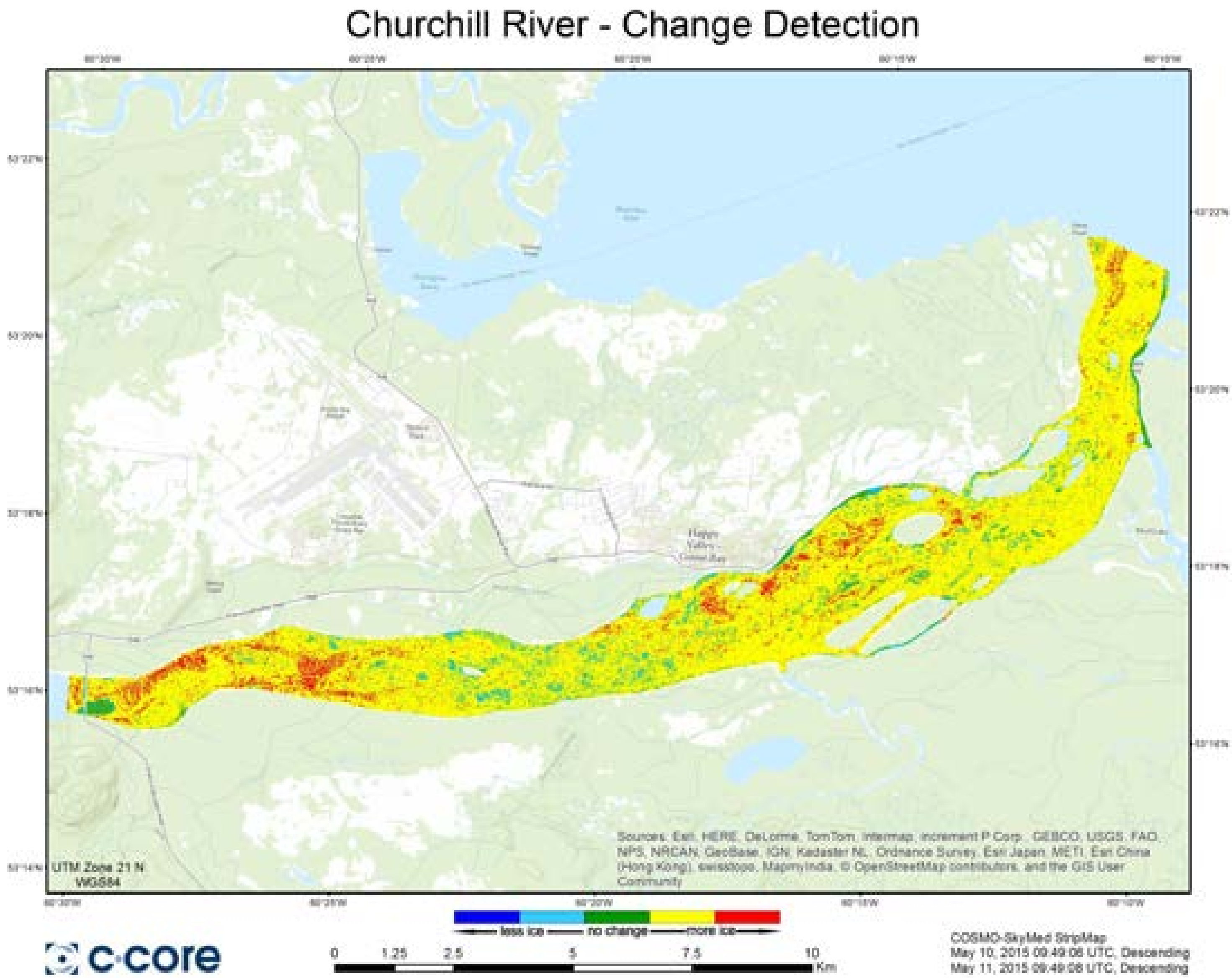

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
1.25
2.5
5
7.5
10
Km
COSMO-SkyMed StripMap Descending
Image acquired May 10, 2015 09:49:08 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
1.25
2.5
5
7.5
10
Km
c·core
COSMO-SkyMed StripMap
May 9, 2015 22:00:05 UTC, Descending
May 10, 2015 09:49:06 UTC, Ascending

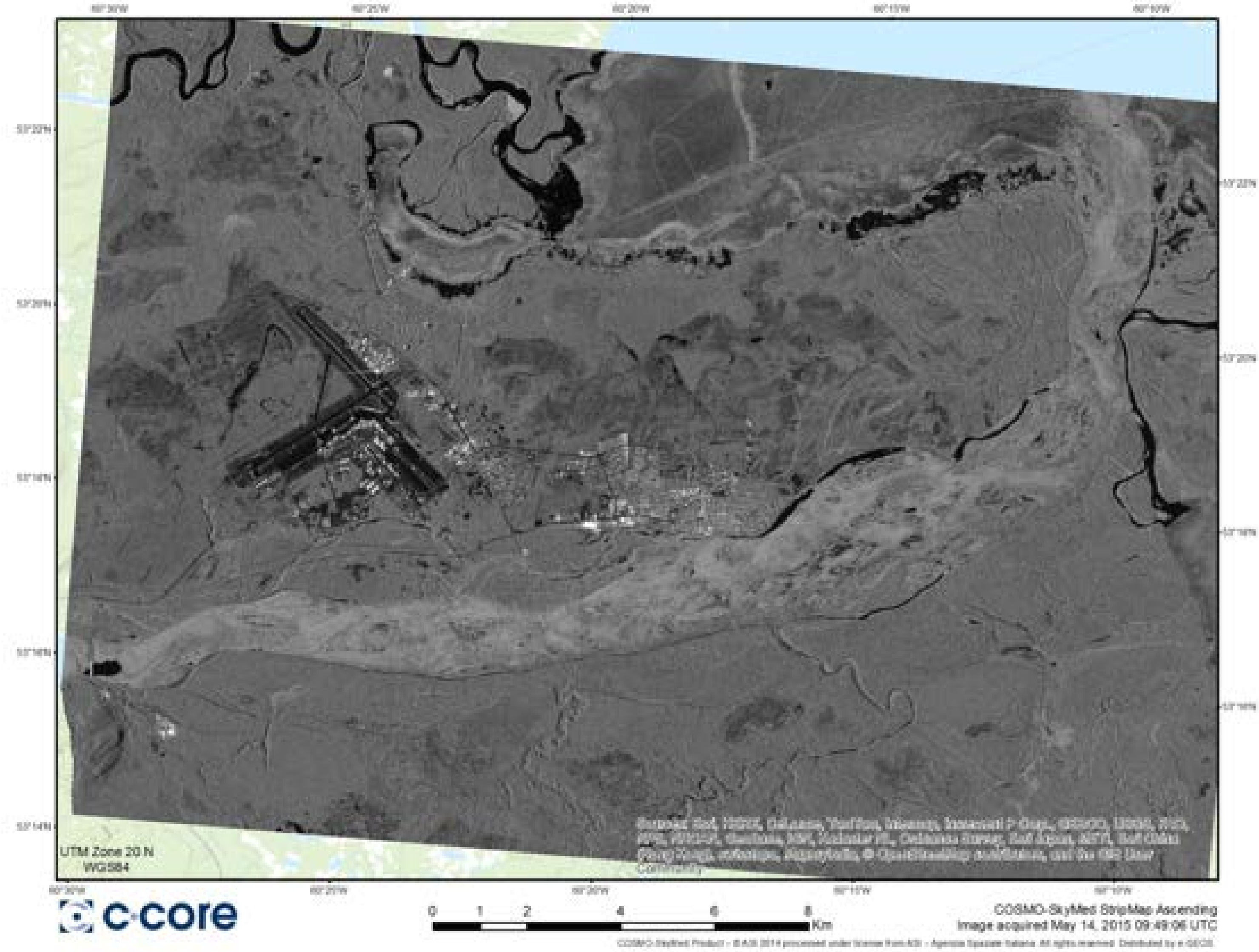

Churchill River - Ice Cover
UTM Zone 20 N
0
1
2
4
6
8
Km
COSMO-SkyMed StripMap Ascending
Image acquired May 11, 2015 09:49:08 UTC

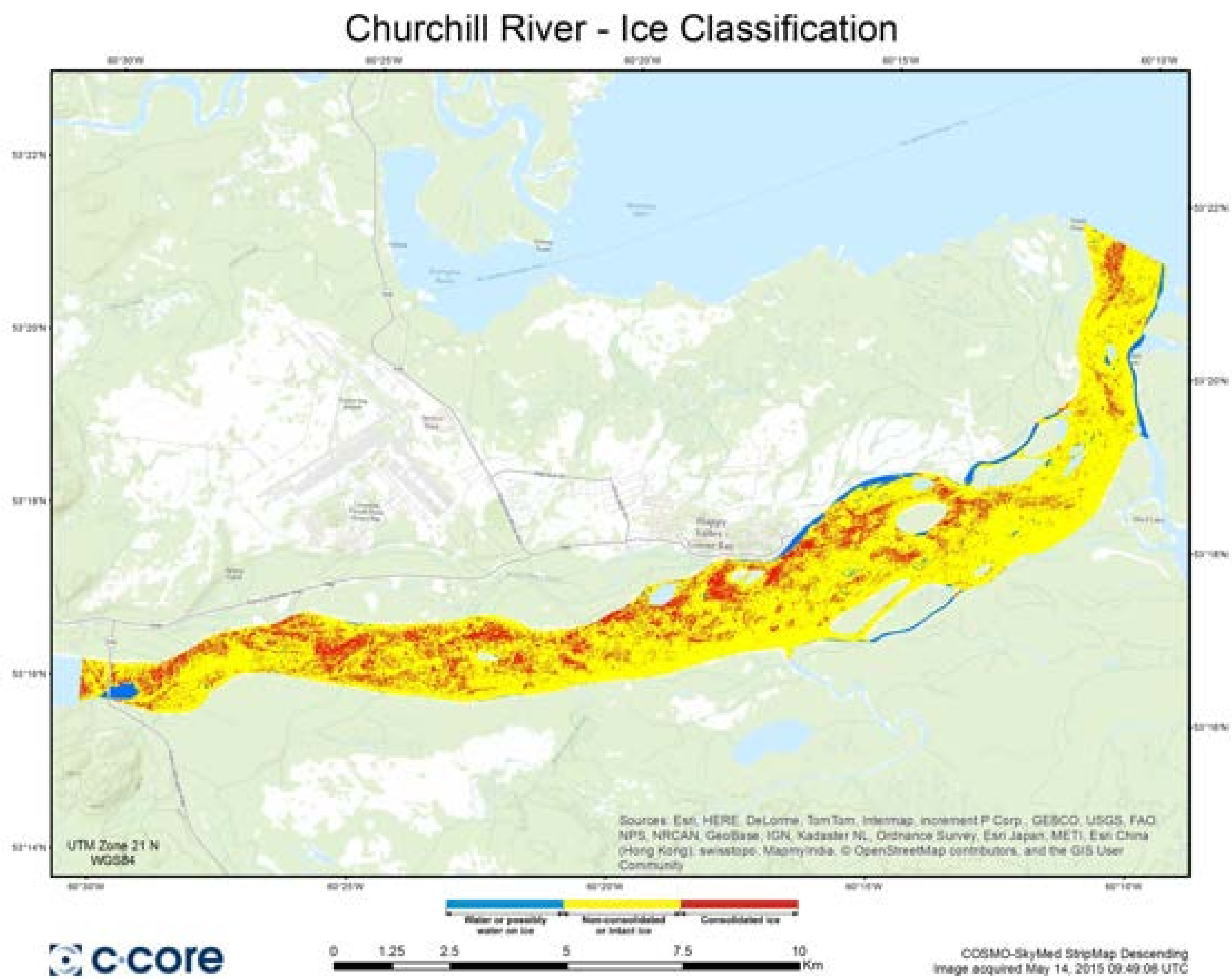
Churchill River - Ice Classification

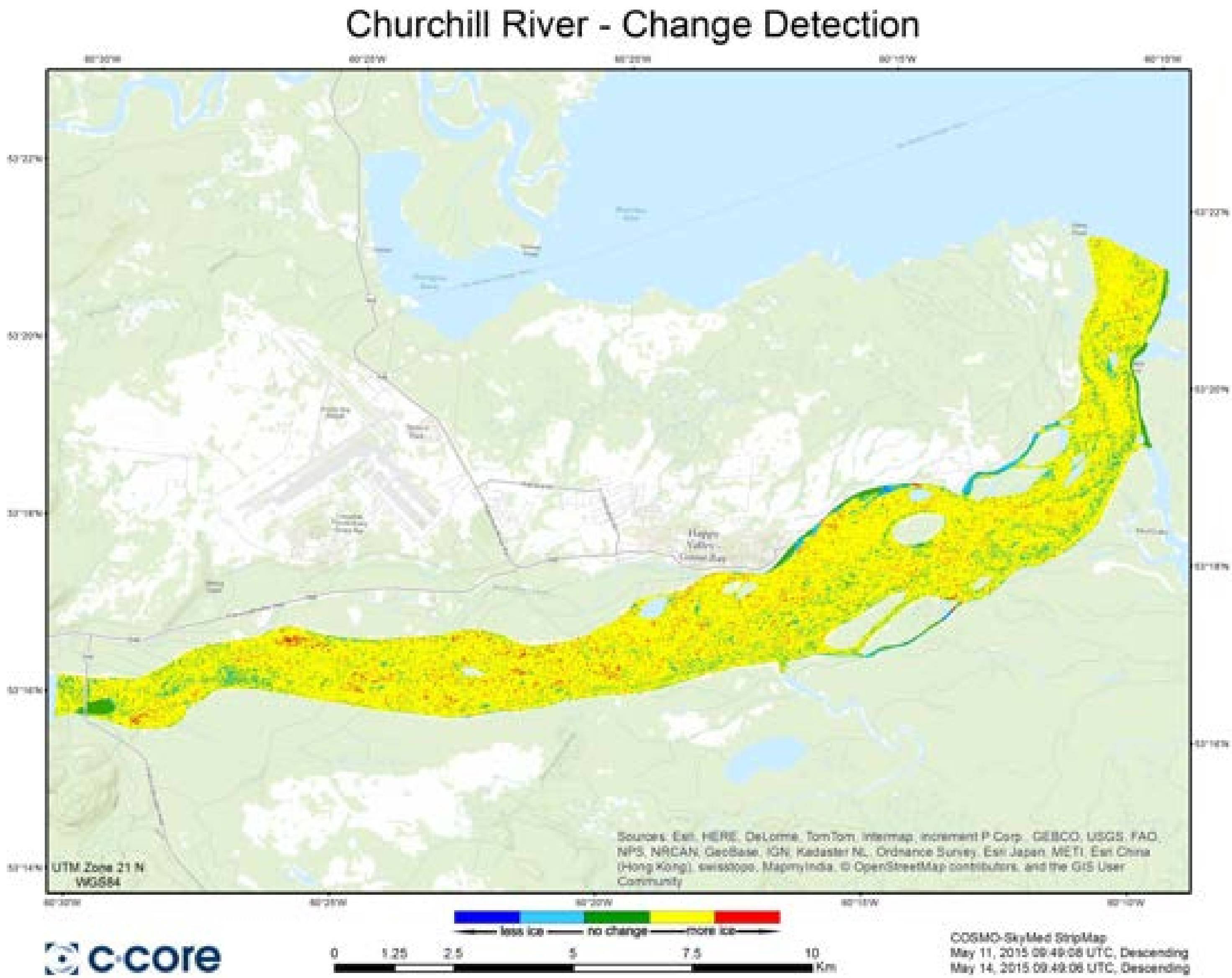


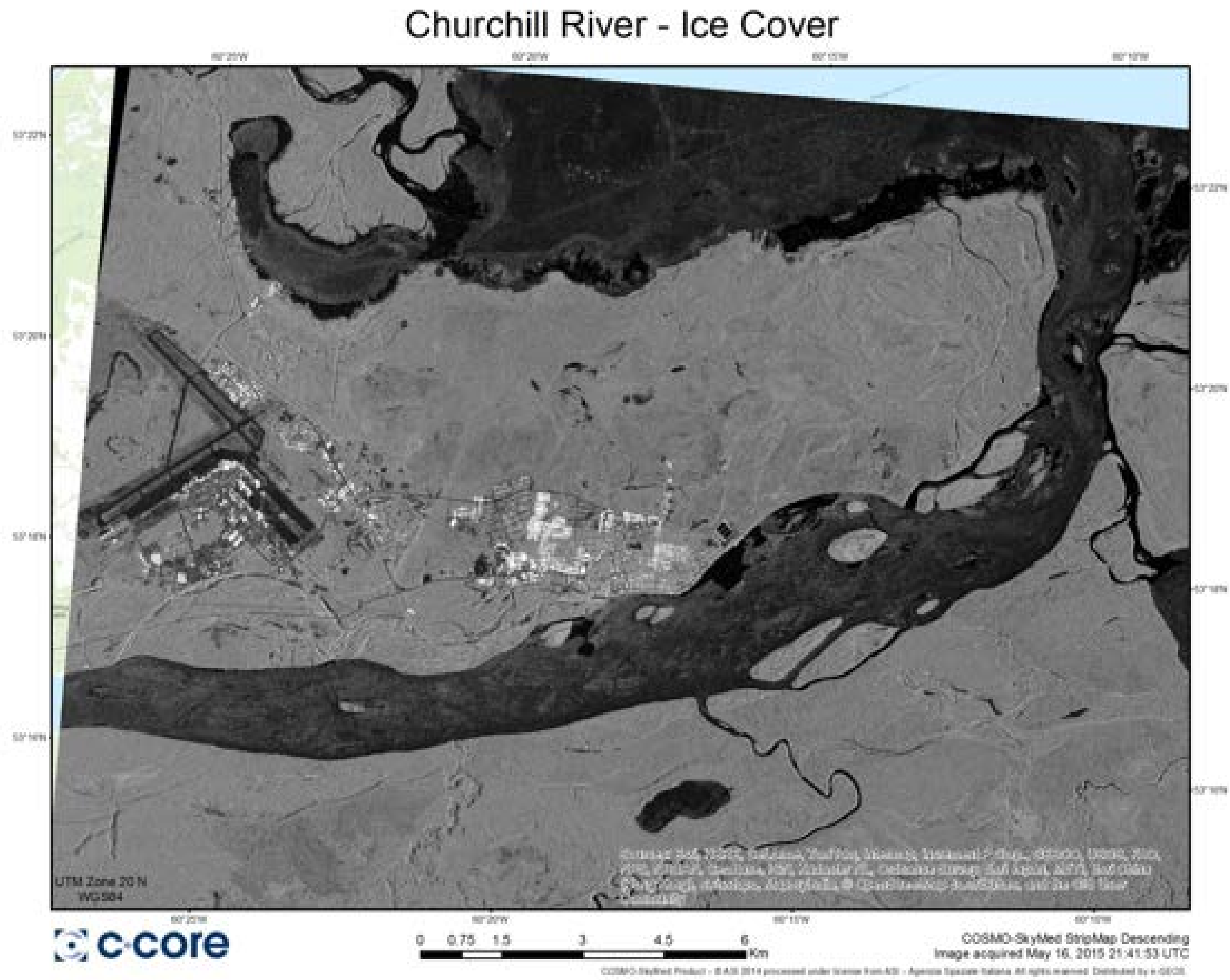

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
1.25
2.5
5
7.5
10
Km
COSMO-SkyMed StripMap
May 10, 2015 09:49:08 UTC, Descending
May 11, 2015 09:49:08 UTC, Descending

Churchill River - Ice Cover

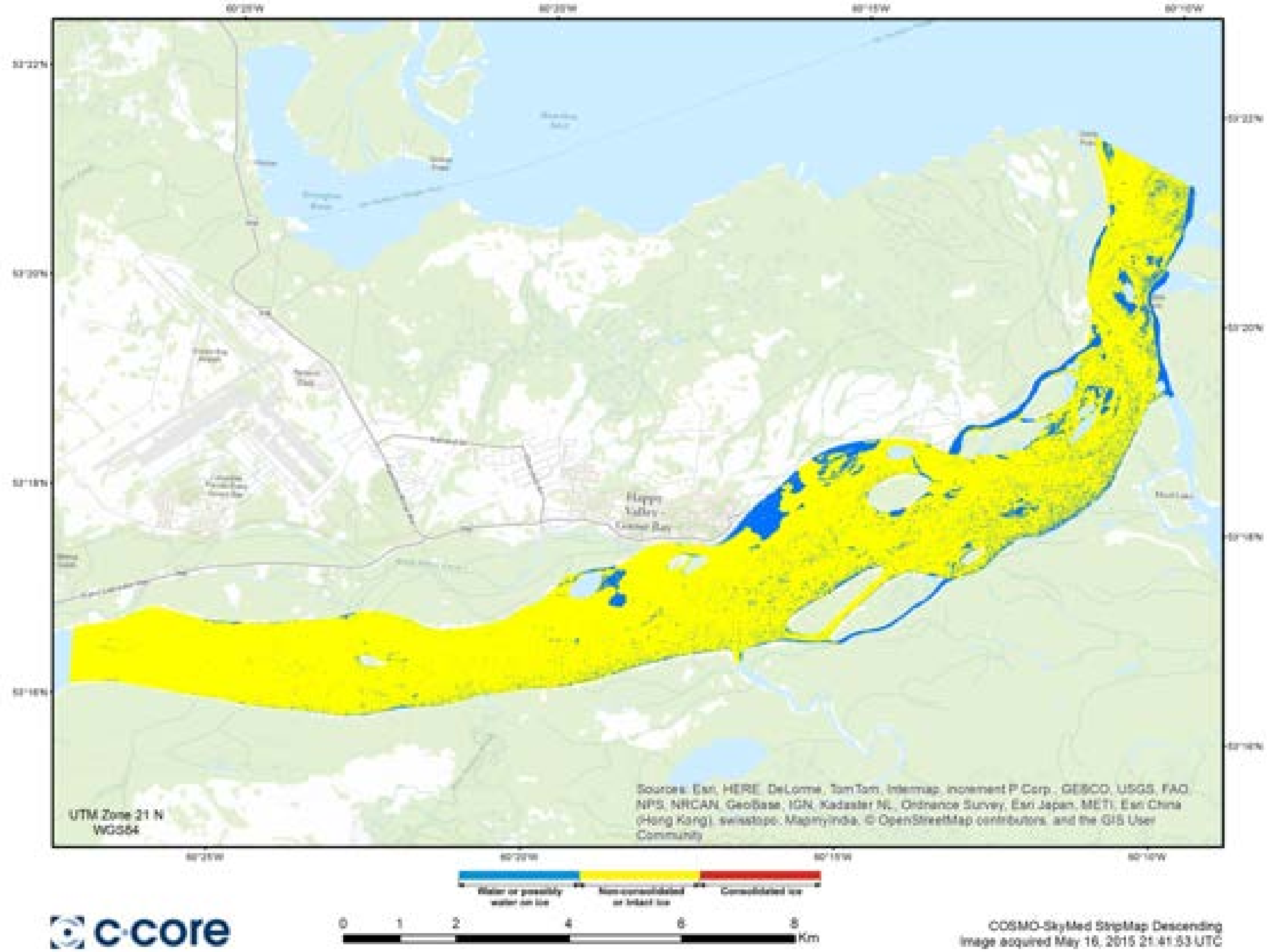



Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or brash ice
Consolidated ice
0
1.25
2.5
5
7.5
10
Km
COSMO-SkyMed StripMap Descending
Image acquired May 14, 2015 09:49:08 UTC

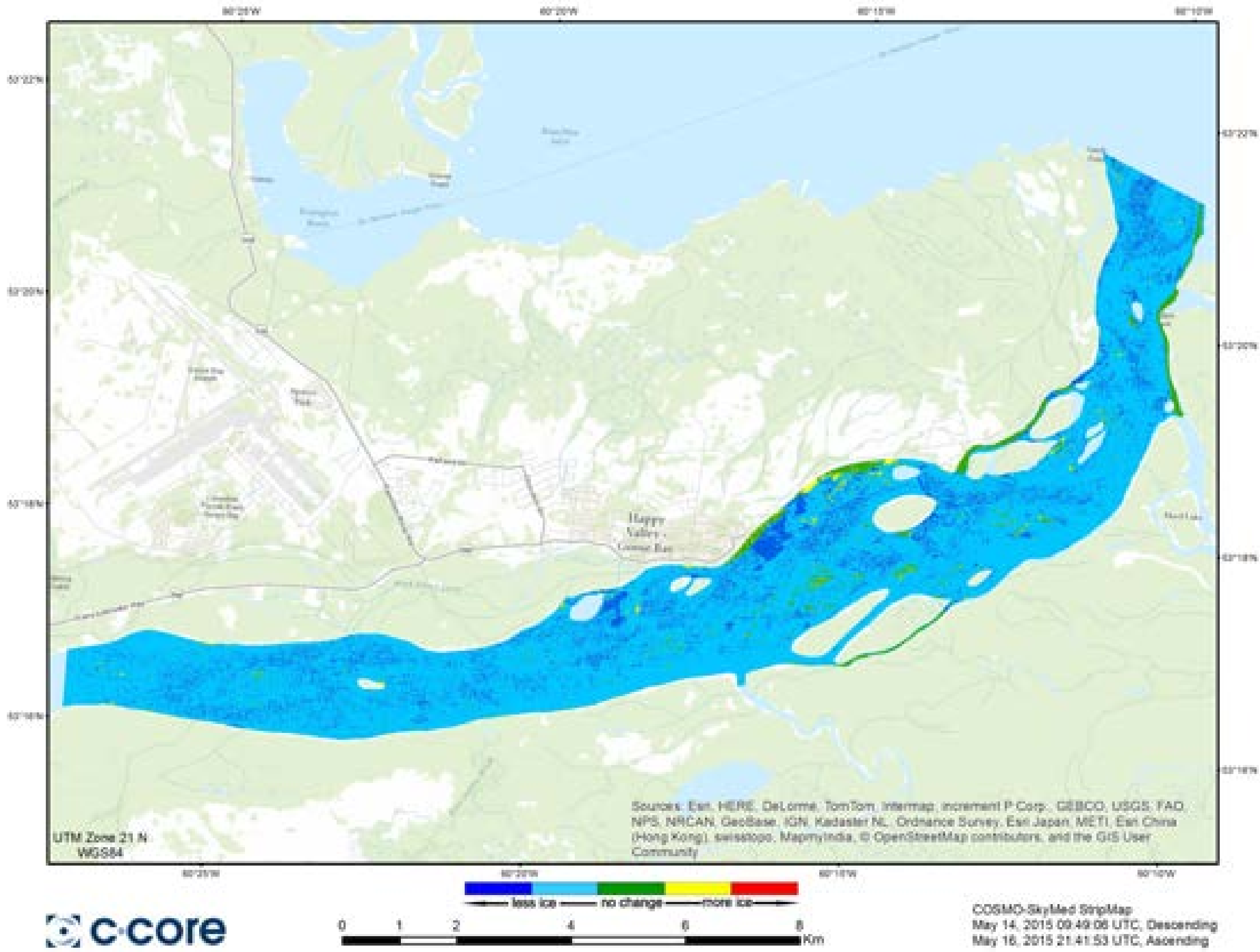

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
1.25
2.5
5
7.5
10
Km
COSMO-SkyMed StripMap
May 11, 2015 09:49:08 UTC, Descending
May 14, 2015 09:49:06 UTC, Descending

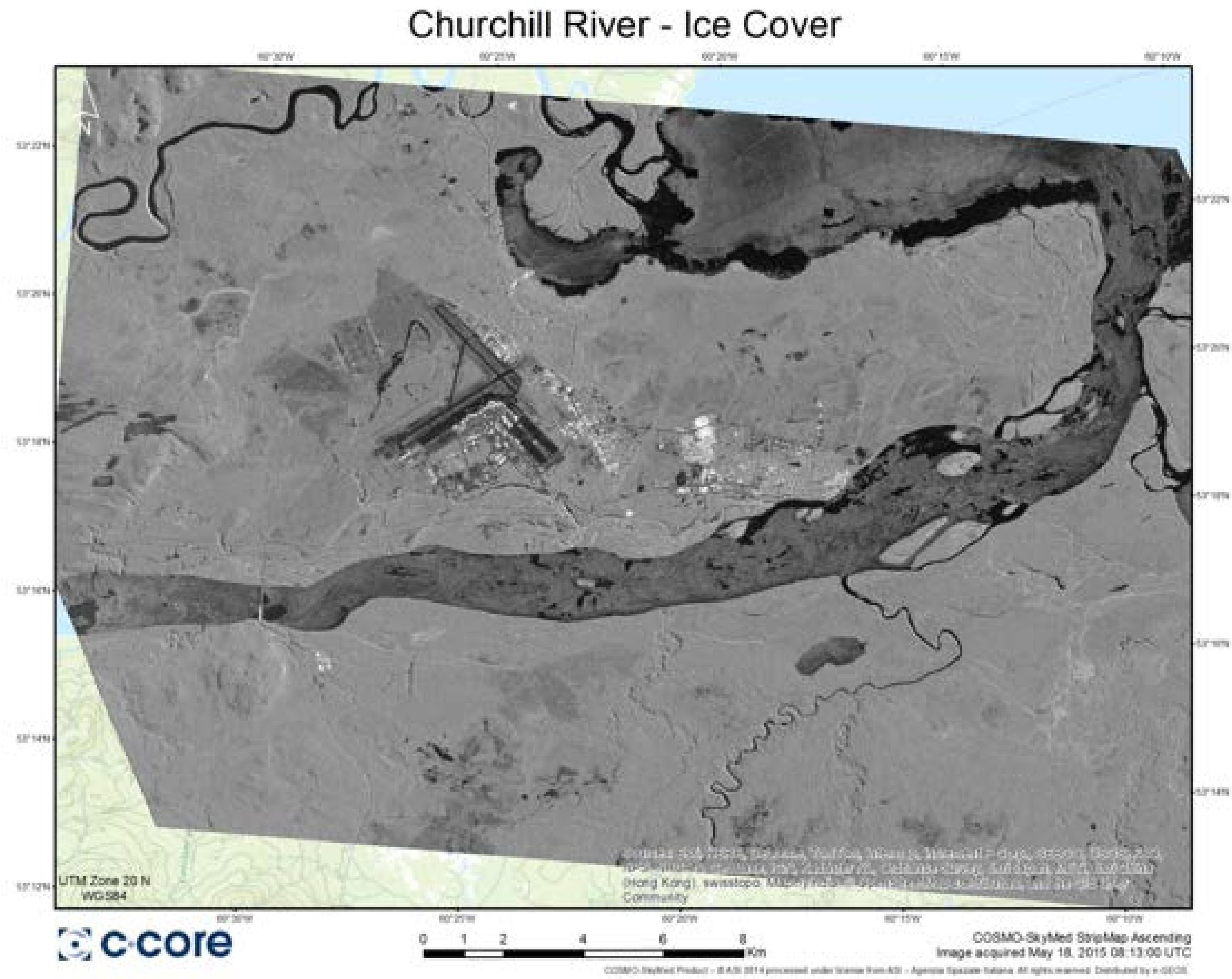

Churchill River - Ice Cover
UTM Zone 20 N
WGS84
0 0.75 1.5 3 4.5 6 Km
COSMO-SkyMed StripMap Descending
Image acquired May 16, 2015 21:41:53 UTC

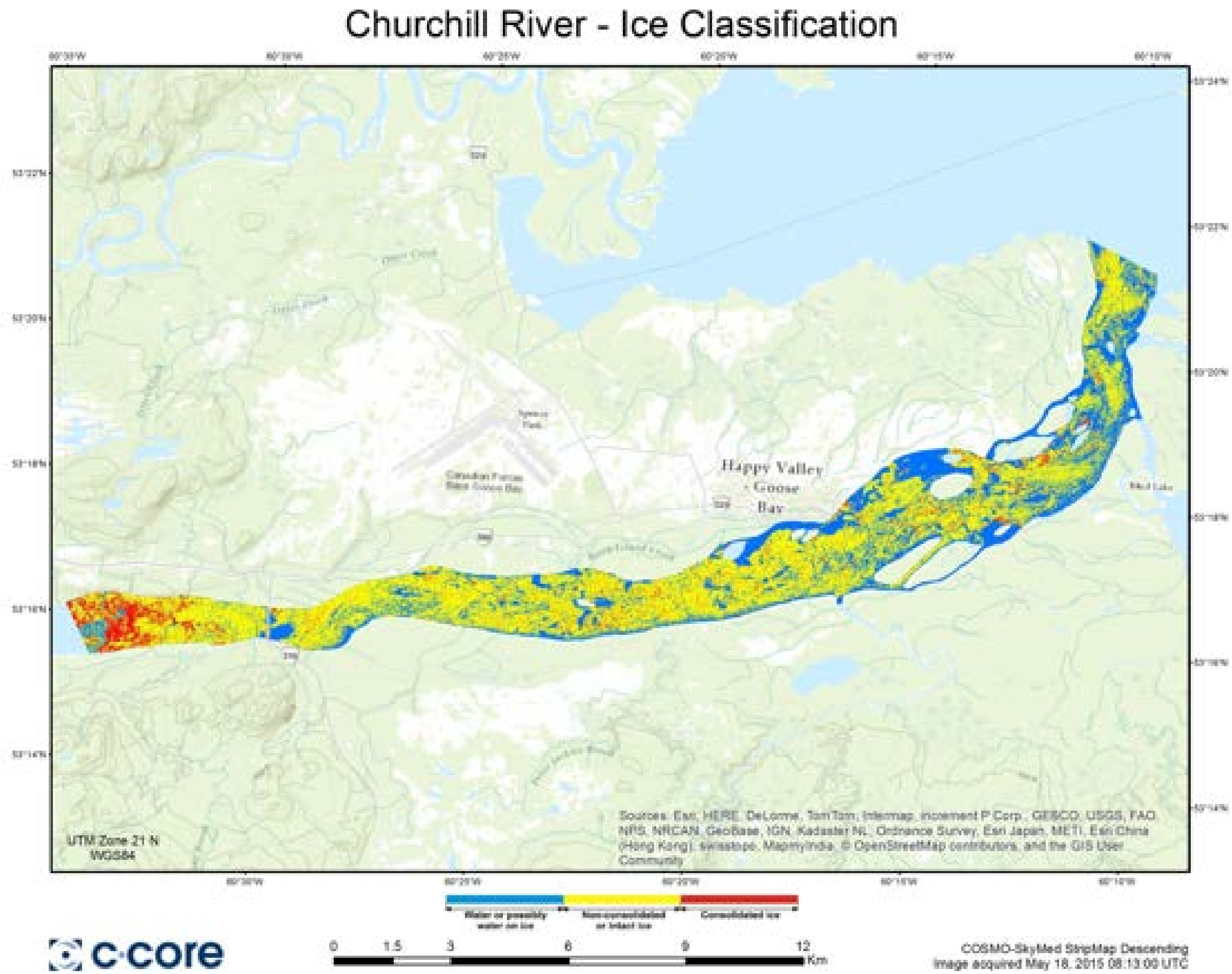
Churchill River - Ice Classification



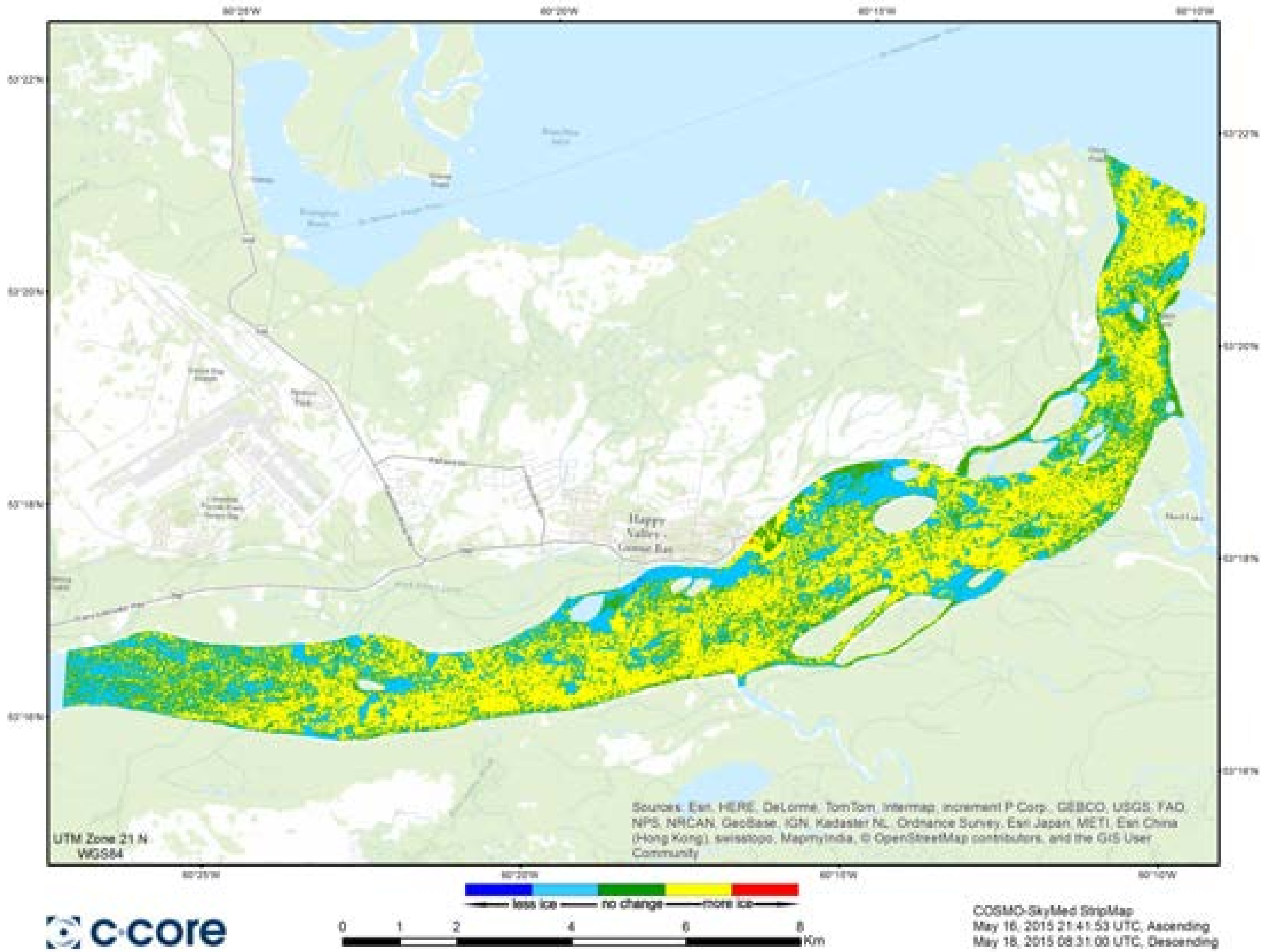
Churchill River - Change Detection

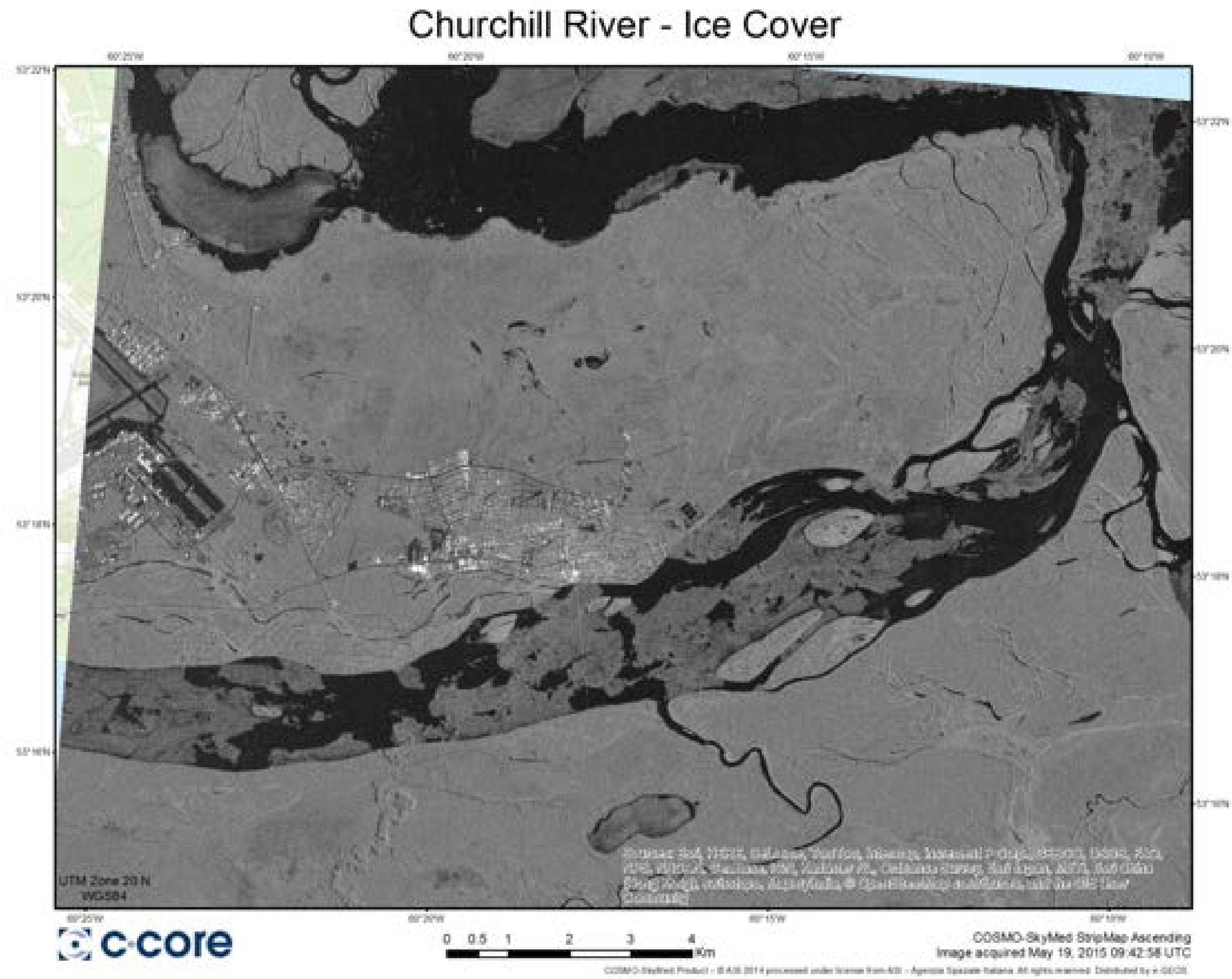


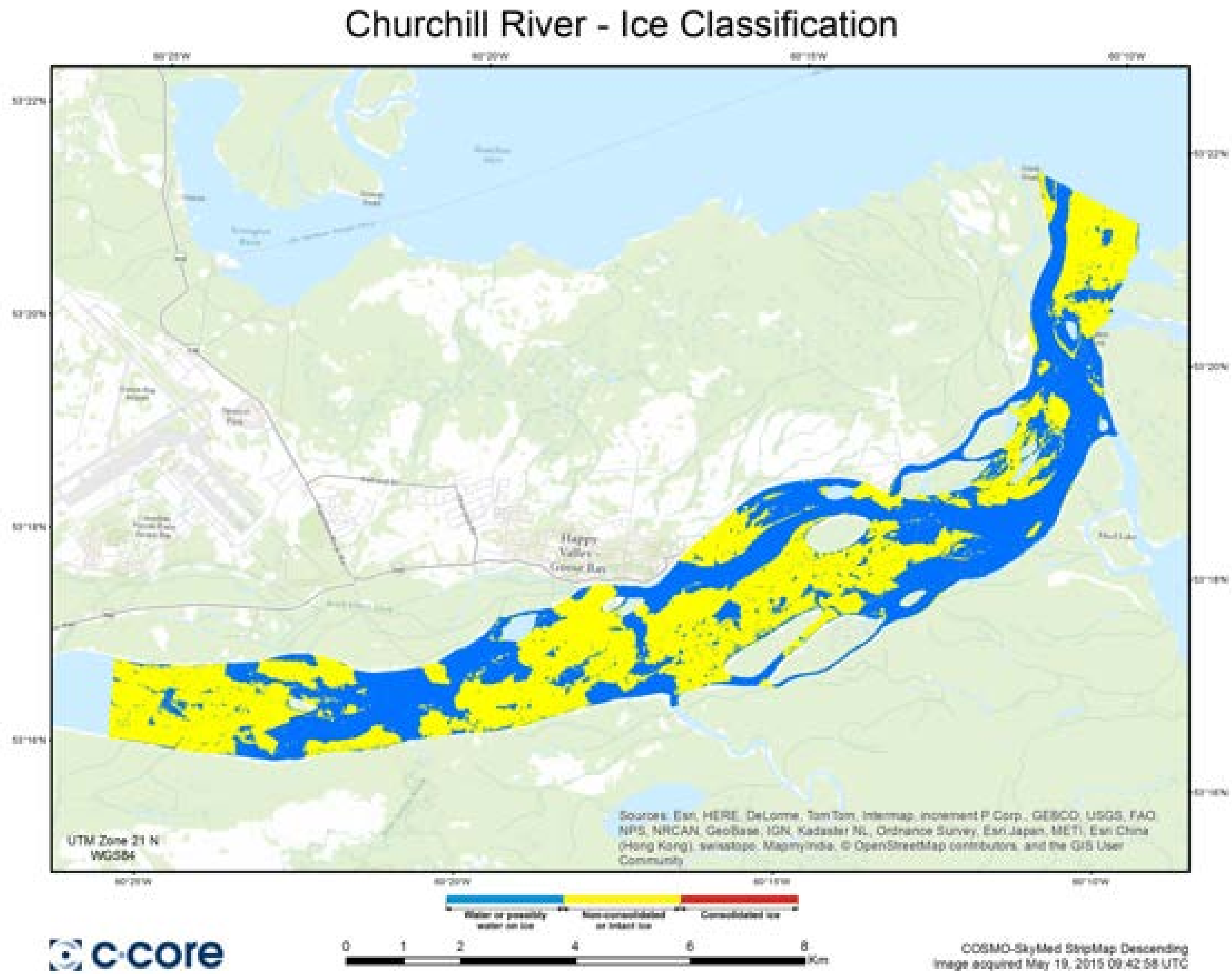

Churchill River - Ice Cover
UTM Zone 20 N
WGS84
0 1 2 4 6 8
Km
COSMO-SkyMed StripMap Ascending
Image acquired May 18, 2015 08:13:00 UTC
COSMO-SkyMed Product - © ASI 2014 processed under license from ASI - Agenzia Spaziale Italiana. All rights reserved. Distributed by e-GEOS.

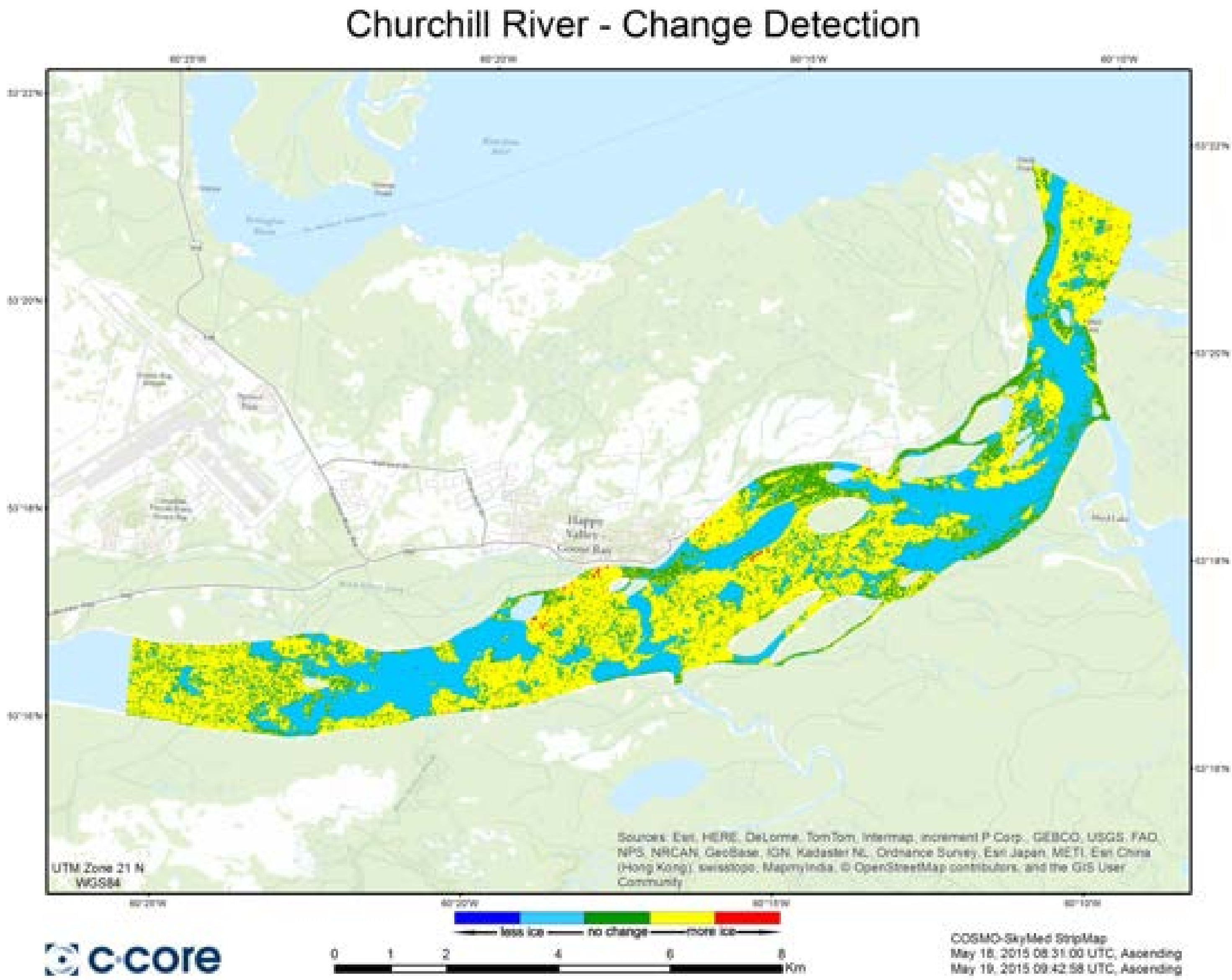

Churchill River - Ice Classification
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 1.5 3 6 9 12 Km
COSMO-SkyMed StripMap Descending
Image acquired May 18, 2015 08:13:00 UTC

Churchill River - Change Detection

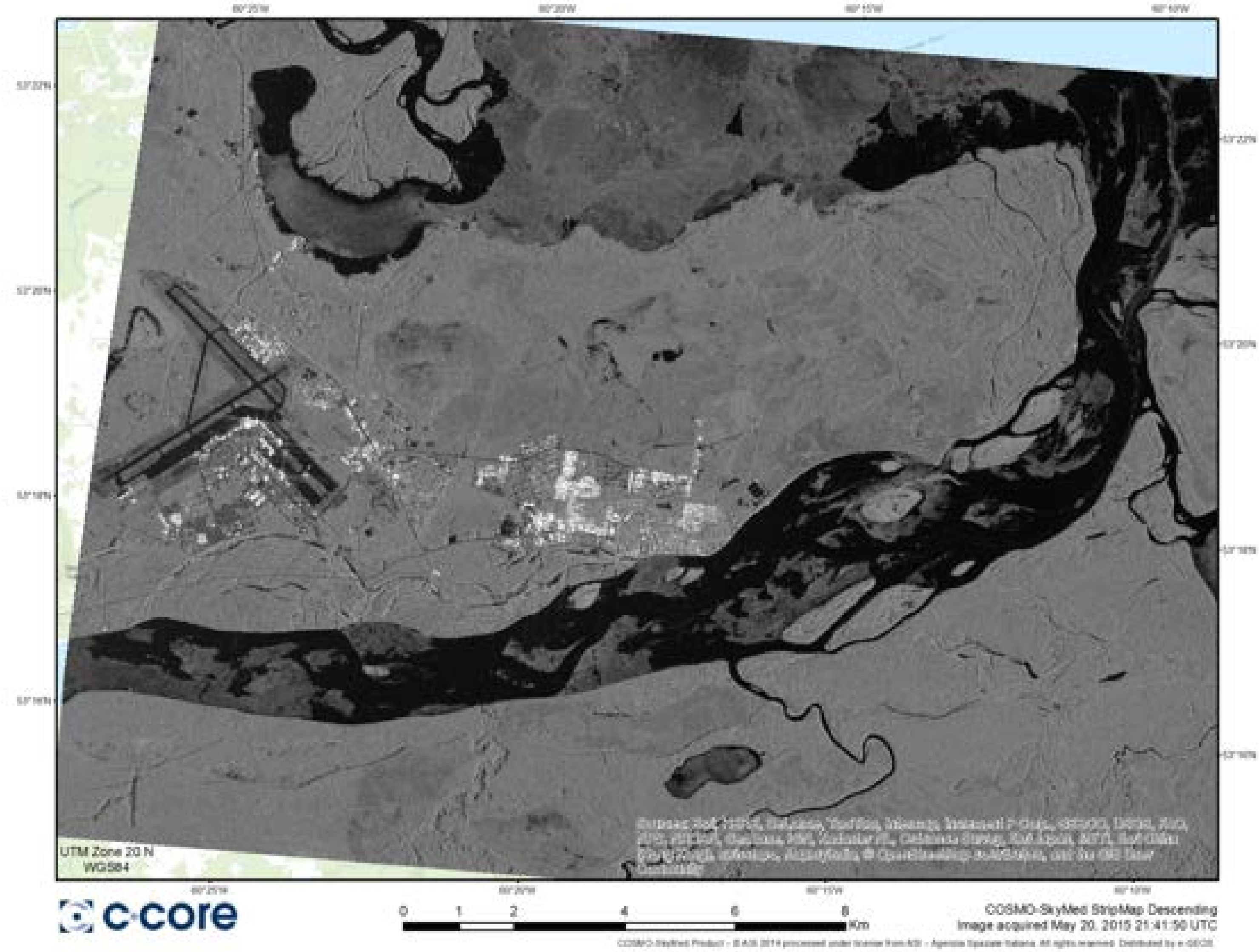


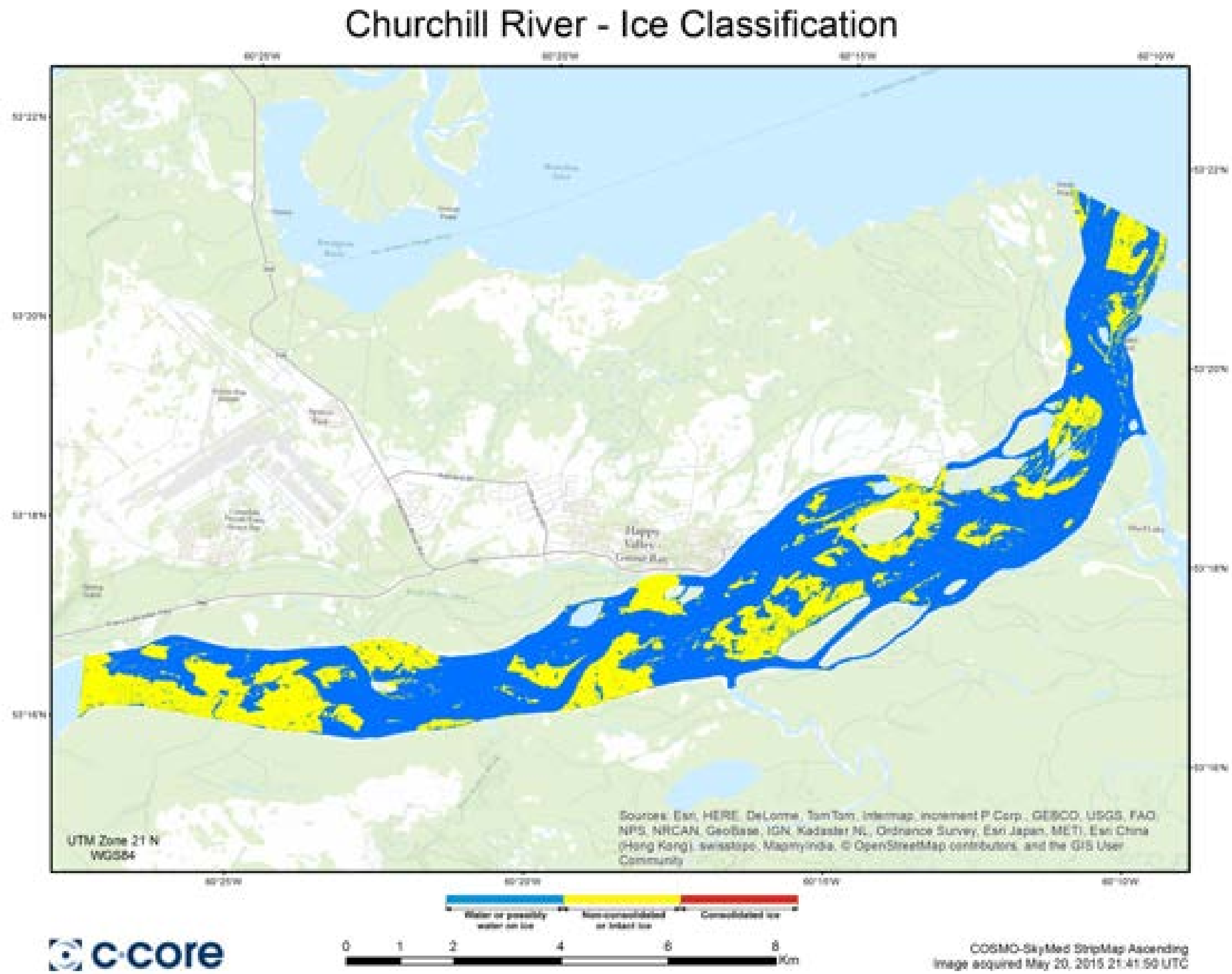

Churchill River - Ice Cover
UTM Zone 20 N
WGS84
0 0.5 1 2 3 4
Km
COSMO-SkyMed StripMap Ascending
Image acquired May 19, 2015 09:42:58 UTC

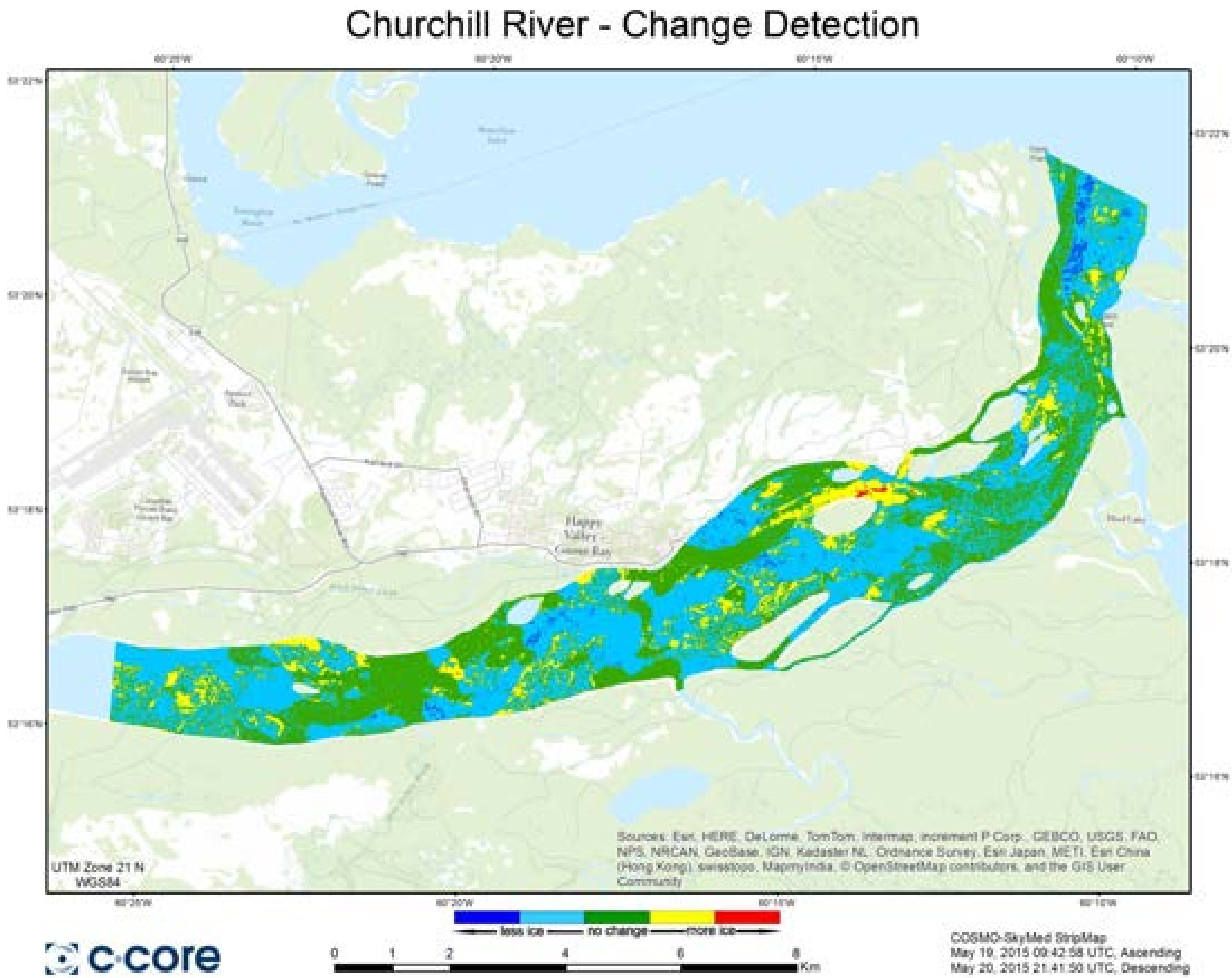

Churchill River - Ice Classification
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
Water or possibly water on ice
Non-consolidated or Intact ice
Consolidated ice
0 1 2 4 6 8 Km
c-core
COSMO-SkyMed StripMap Descending
Image acquired May 19, 2015 09:42:58 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
1
2
4
6
8
Km
c-core
COSMO-SkyMed StripMap
May 18, 2015 08:31:00 UTC, Ascending
May 19, 2015 09:42:58 UTC, Ascending

Churchill River - Ice Cover

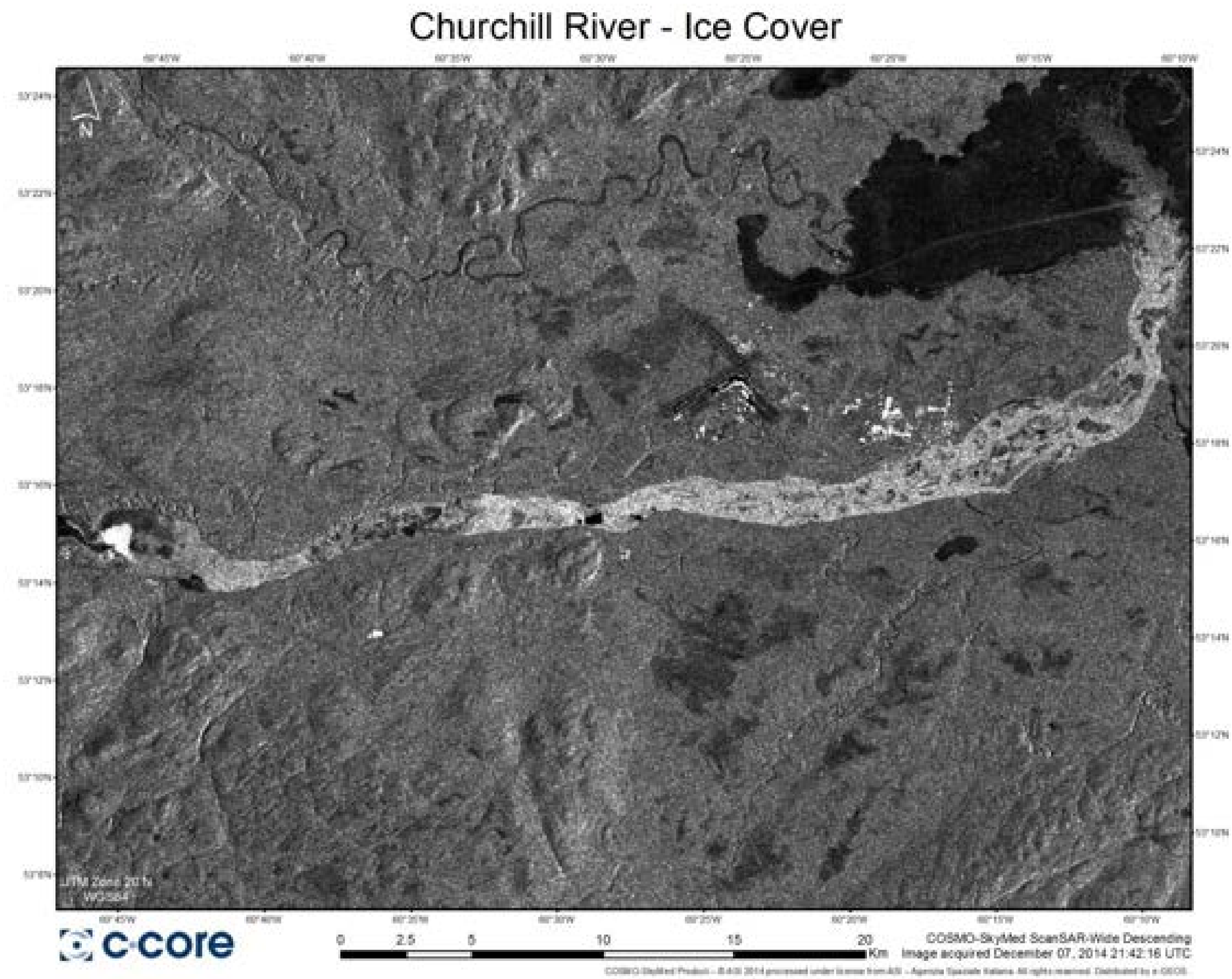


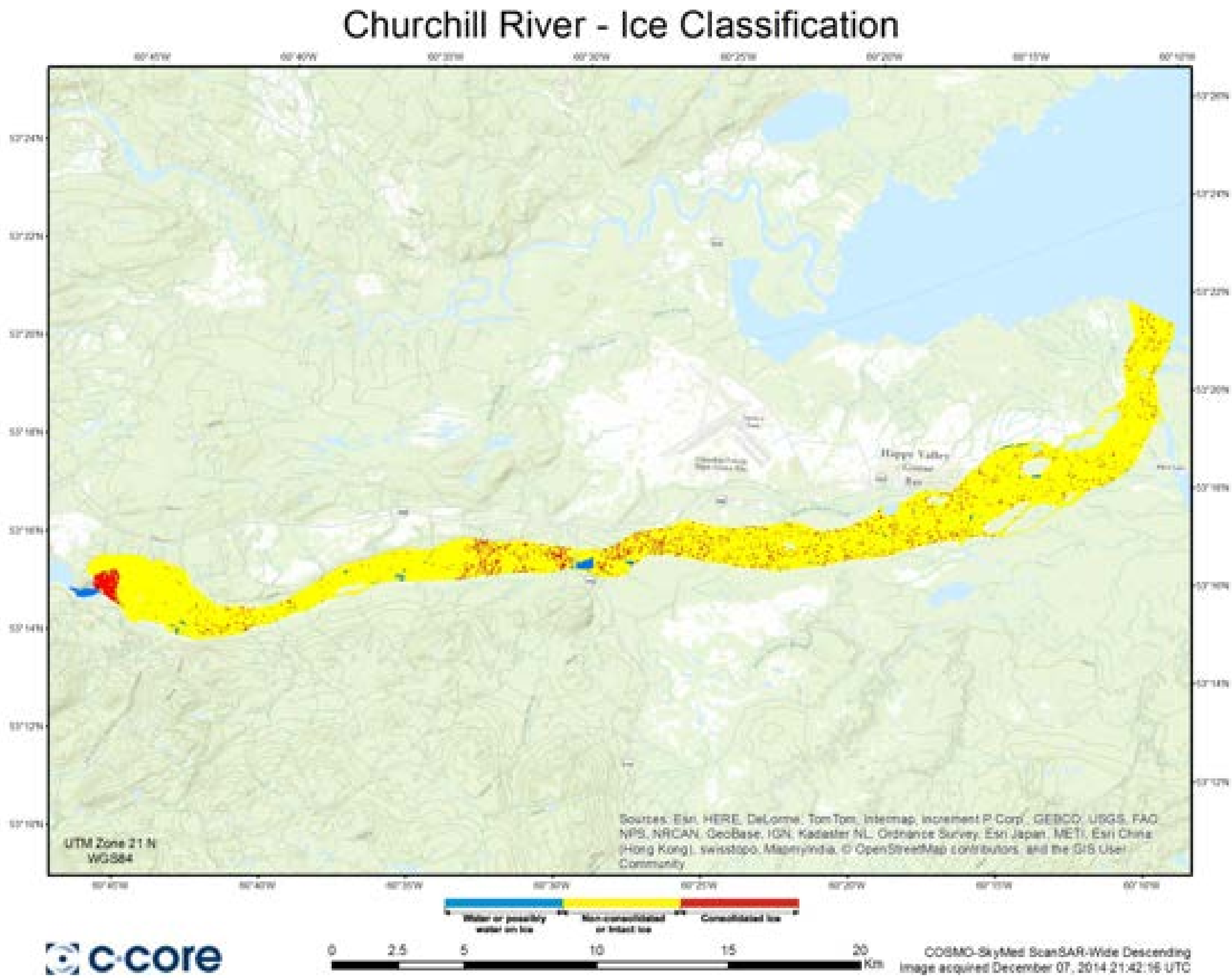

Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 1 2 4 6 8 Km
COSMO-SkyMed StripMap Ascending
Image acquired May 20, 2015 21:41:50 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0 1 2 4 6 8
Km
COSMO-SkyMed StripMap
May 19, 2015 09:42:58 UTC, Ascending
May 20, 2015 21:41:50 UTC, Descending

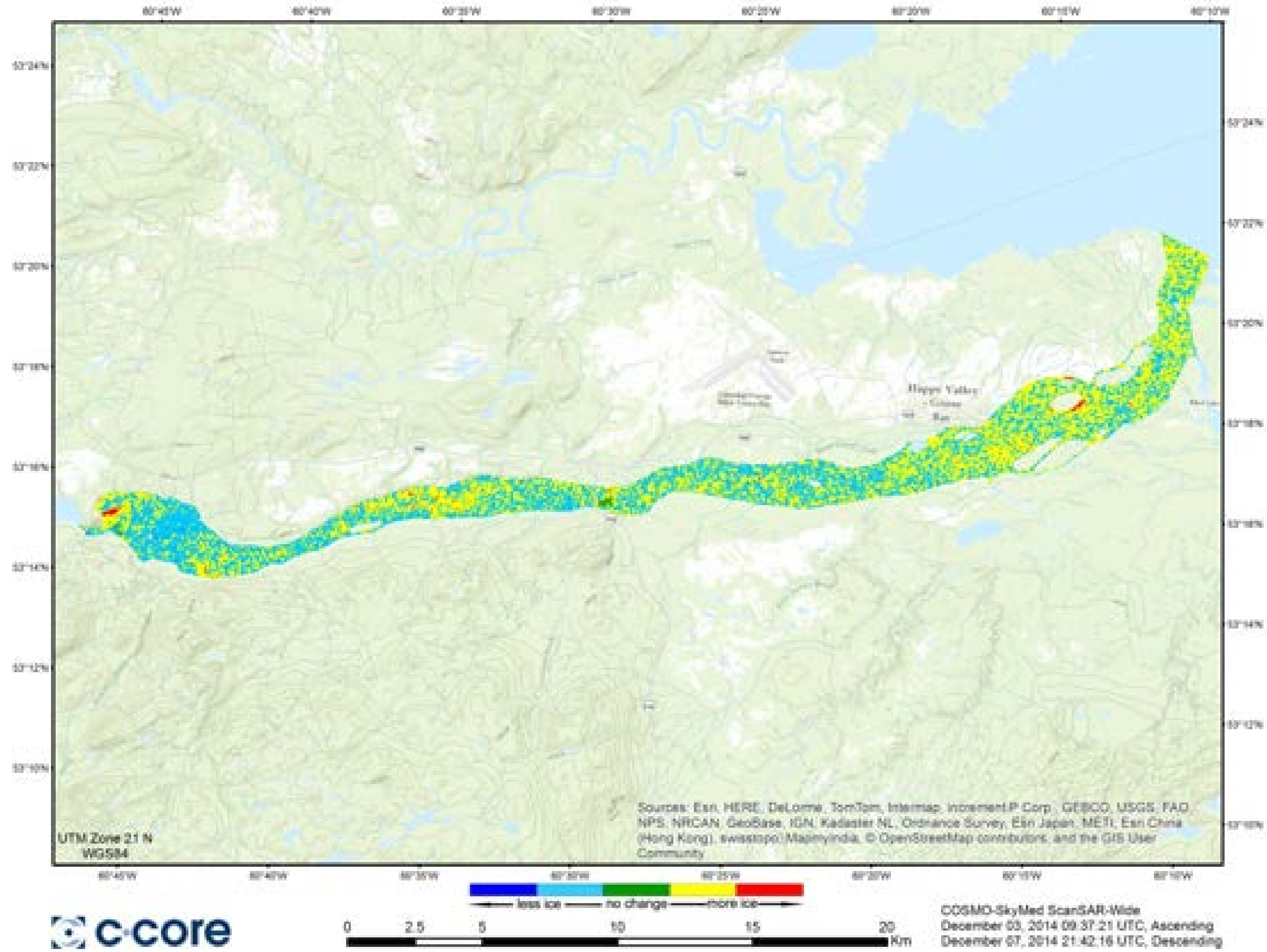
APPENDIX D

Lower Churchill River Seasonal Ice Monitoring

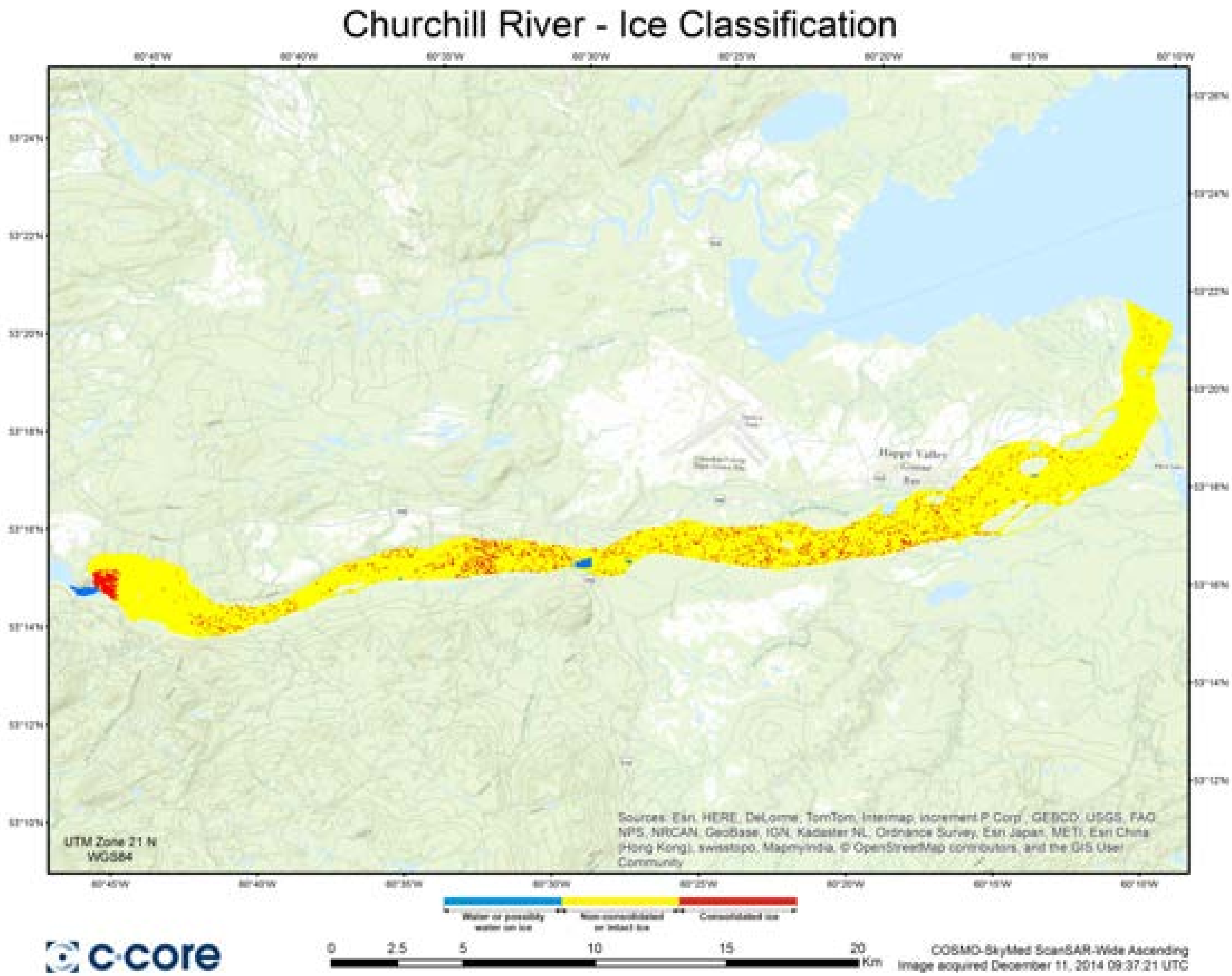

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
c-core
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired December 07, 2014 21:42:16 UTC

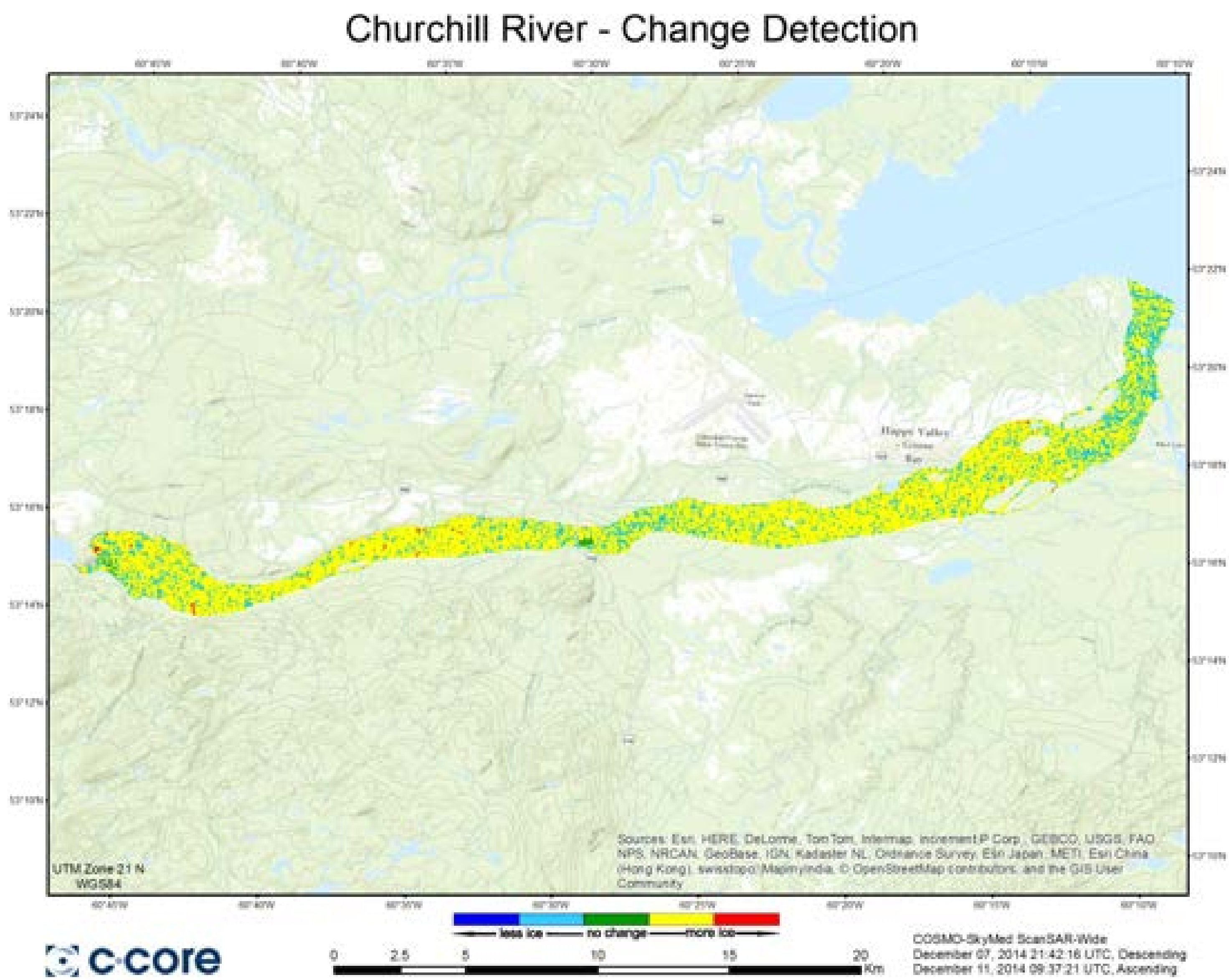

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired December 07, 2014 21:42:16 UTC

Churchill River - Change Detection

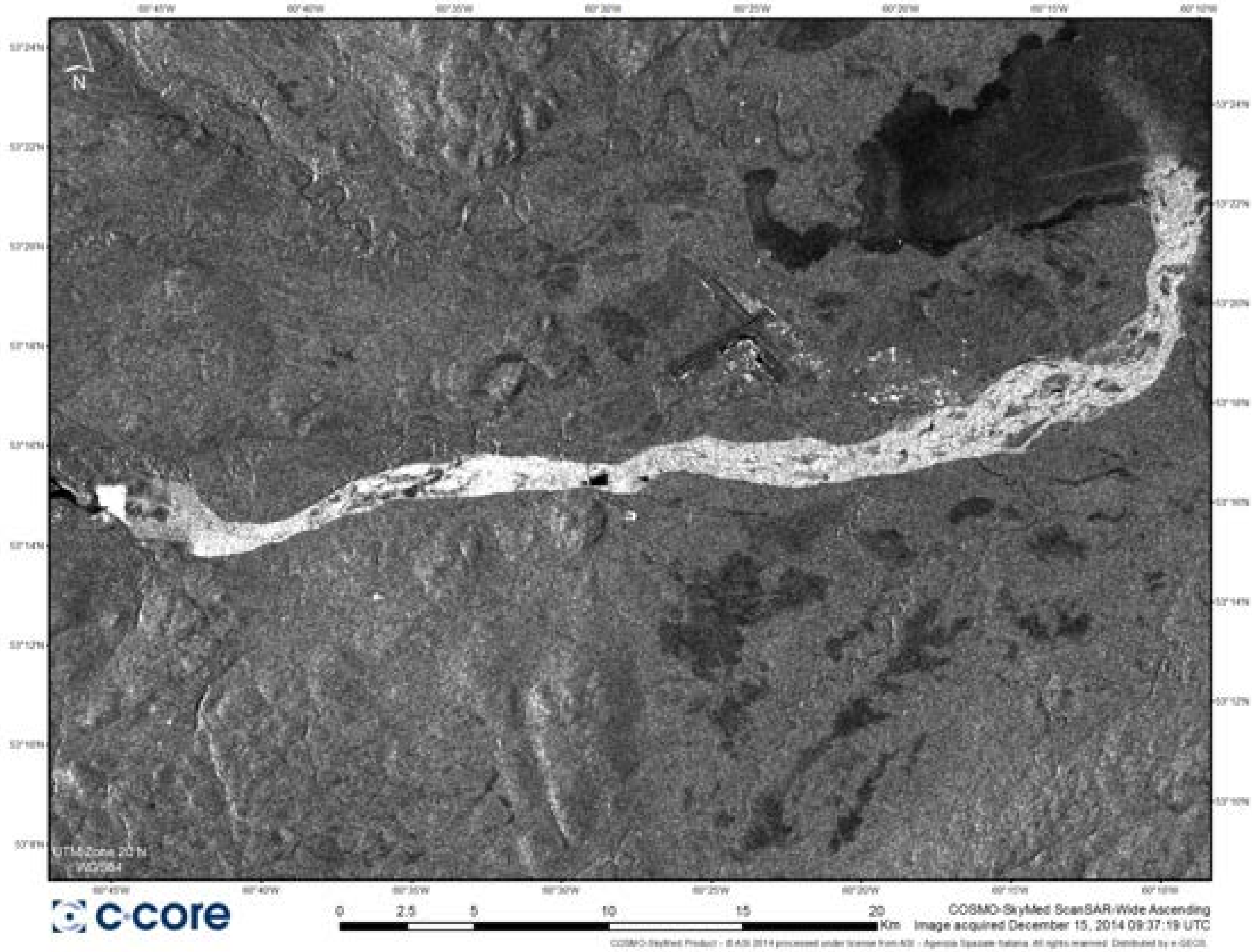


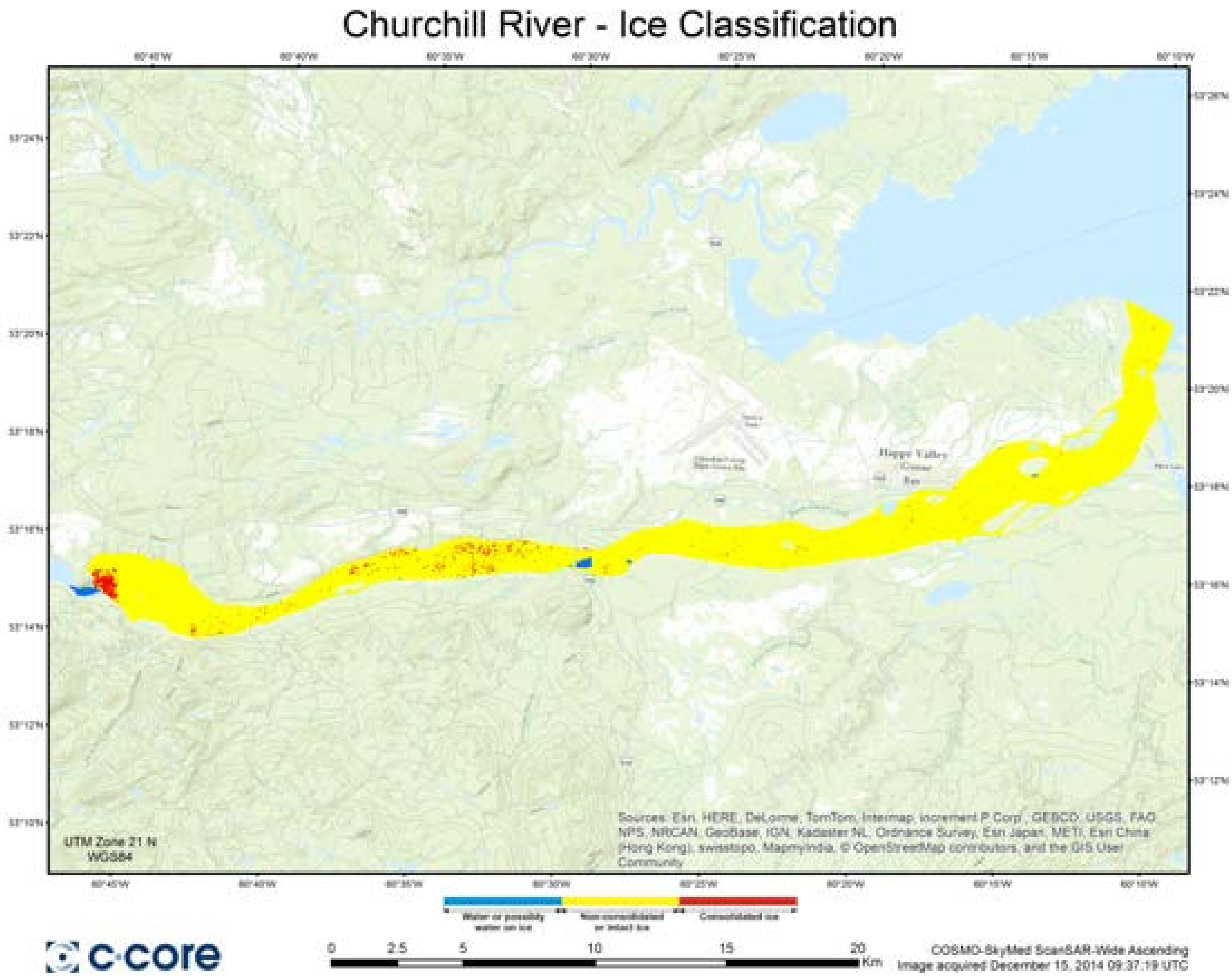

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 11, 2014 09:37:21 UTC

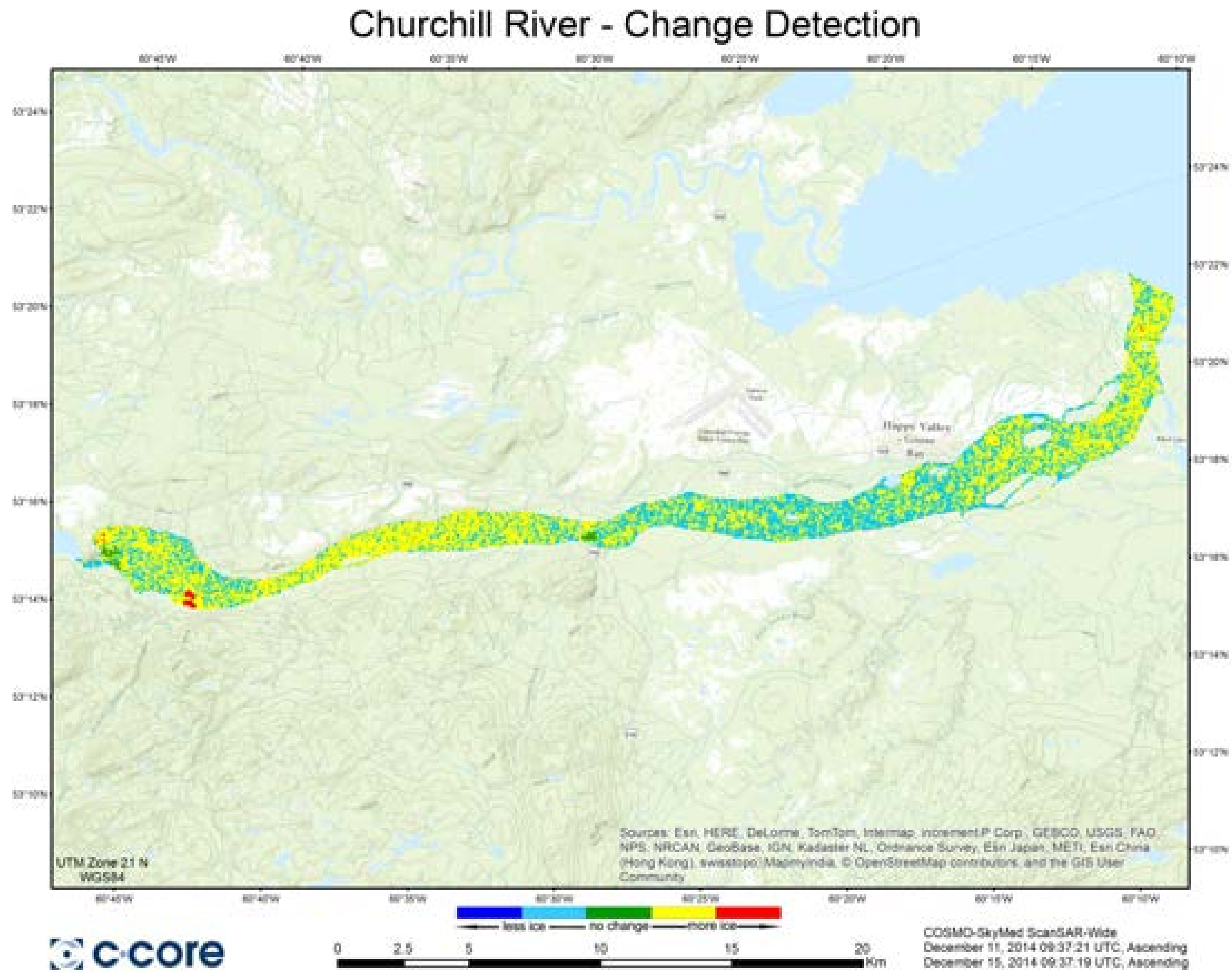

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Happy Valley
Goose
Bay
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
c·core
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 11, 2014 09:37:21 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
c·core
COSMO-SkyMed ScanSAR-Wide
December 07, 2014 21:42:16 UTC, Descending
December 11, 2014 09:37:21 UTC, Ascending

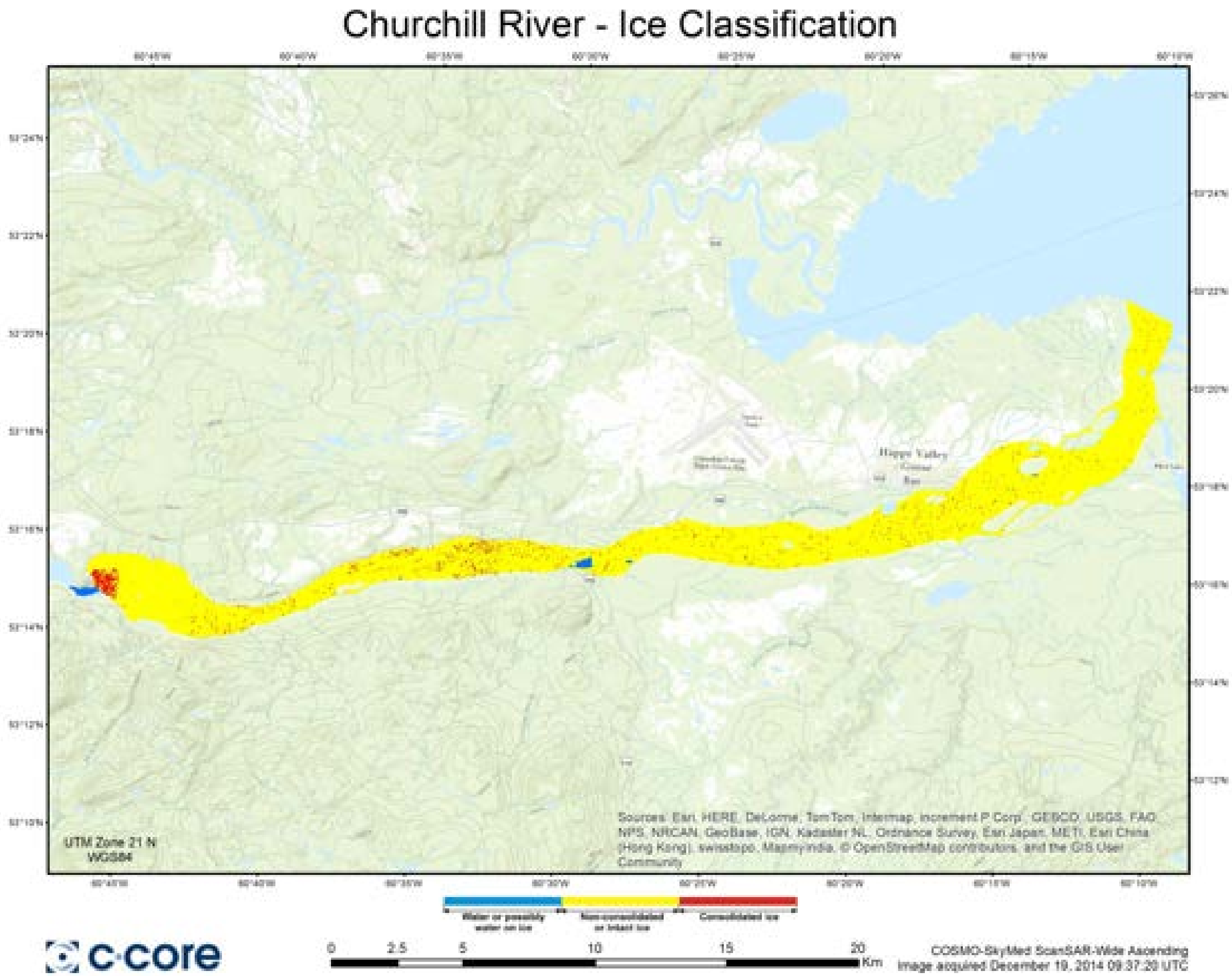
Churchill River - Ice Cover

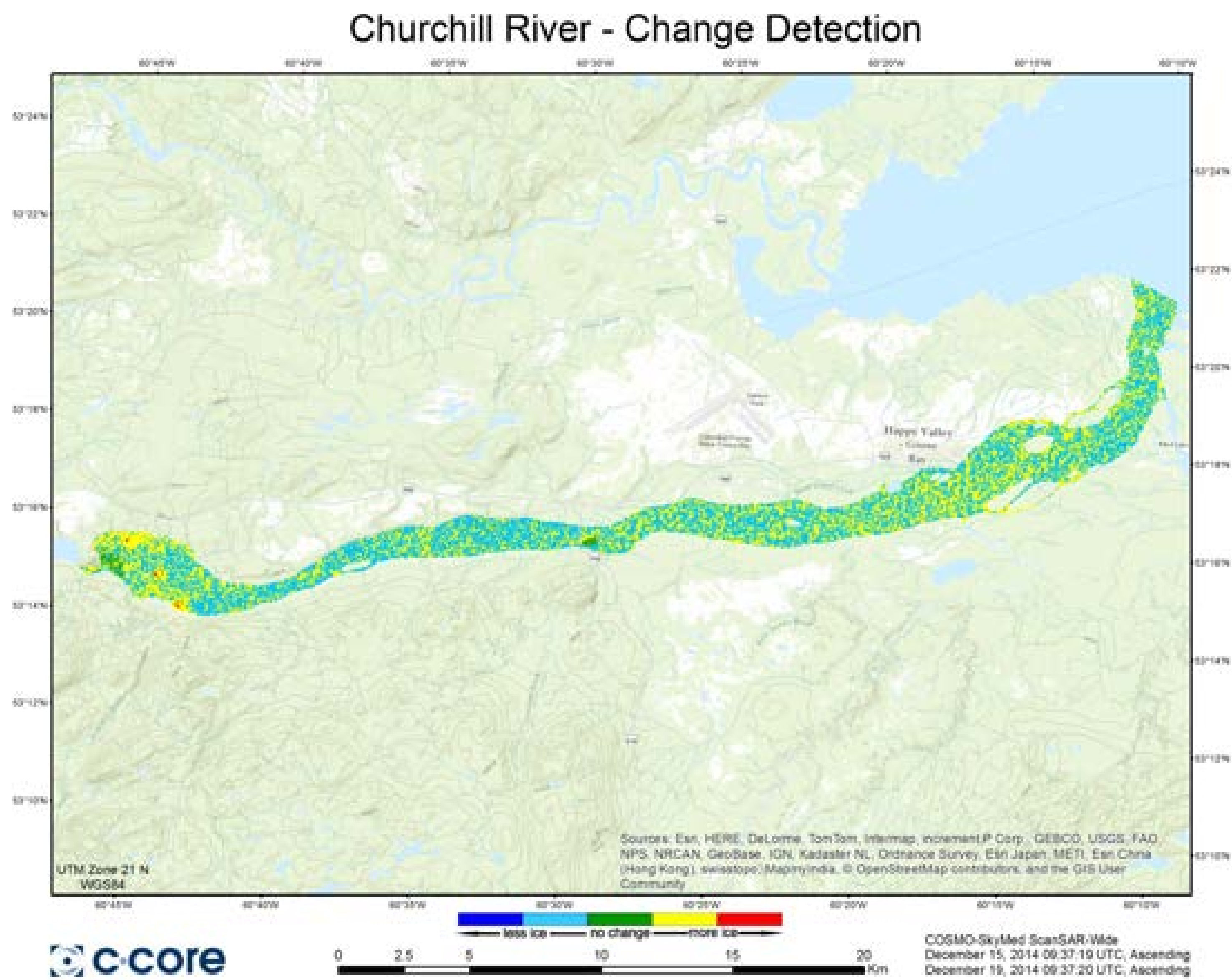



Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 15, 2014 09:37:19 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
December 11, 2014 09:37:21 UTC, Ascending
December 15, 2014 09:37:19 UTC, Ascending

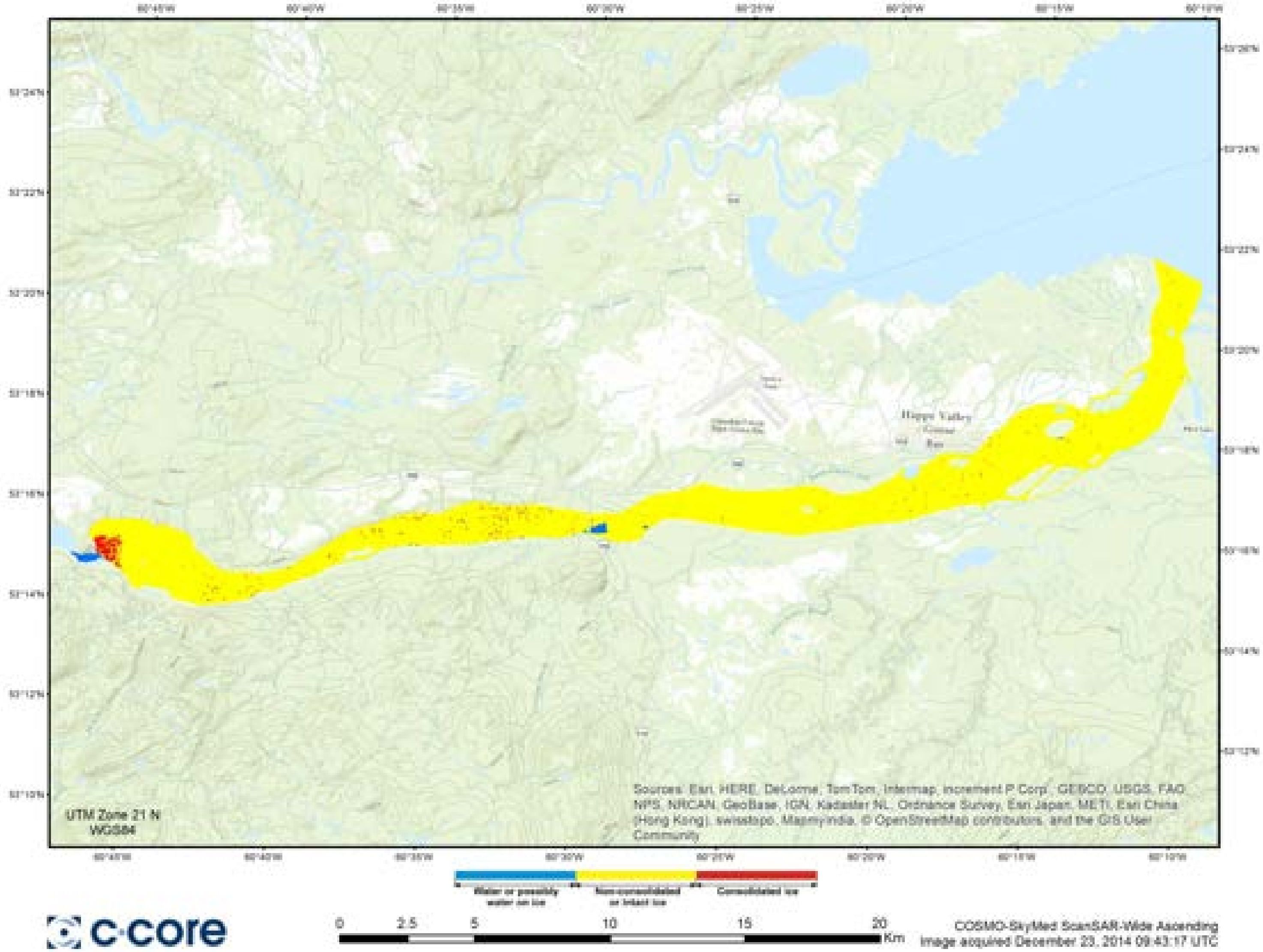

Churchill River - Ice Cover
N
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 19, 2014 09:37:20 UTC

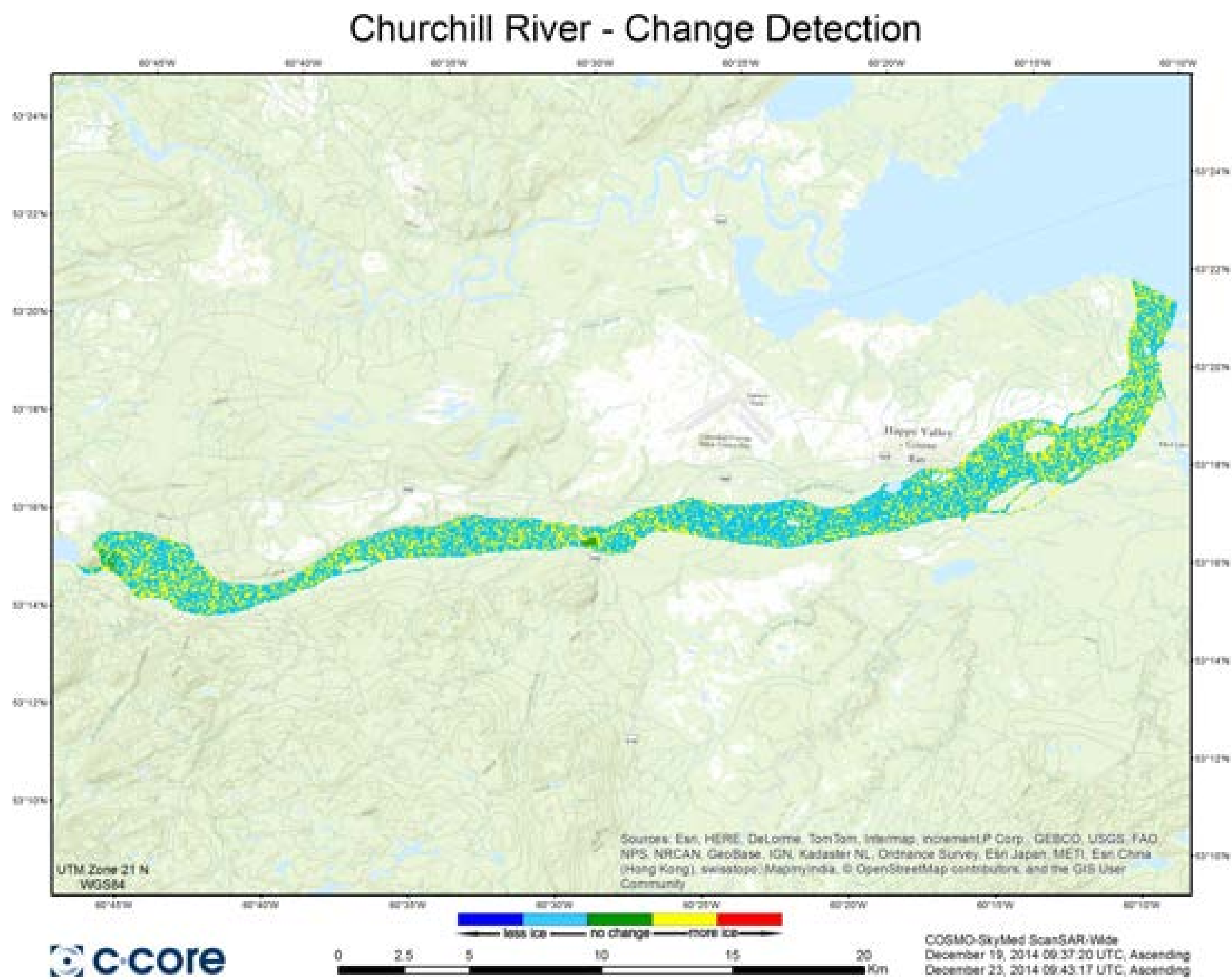

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 19, 2014 09:37:20 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
December 15, 2014 09:37:19 UTC, Ascending
December 19, 2014 09:37:20 UTC, Ascending

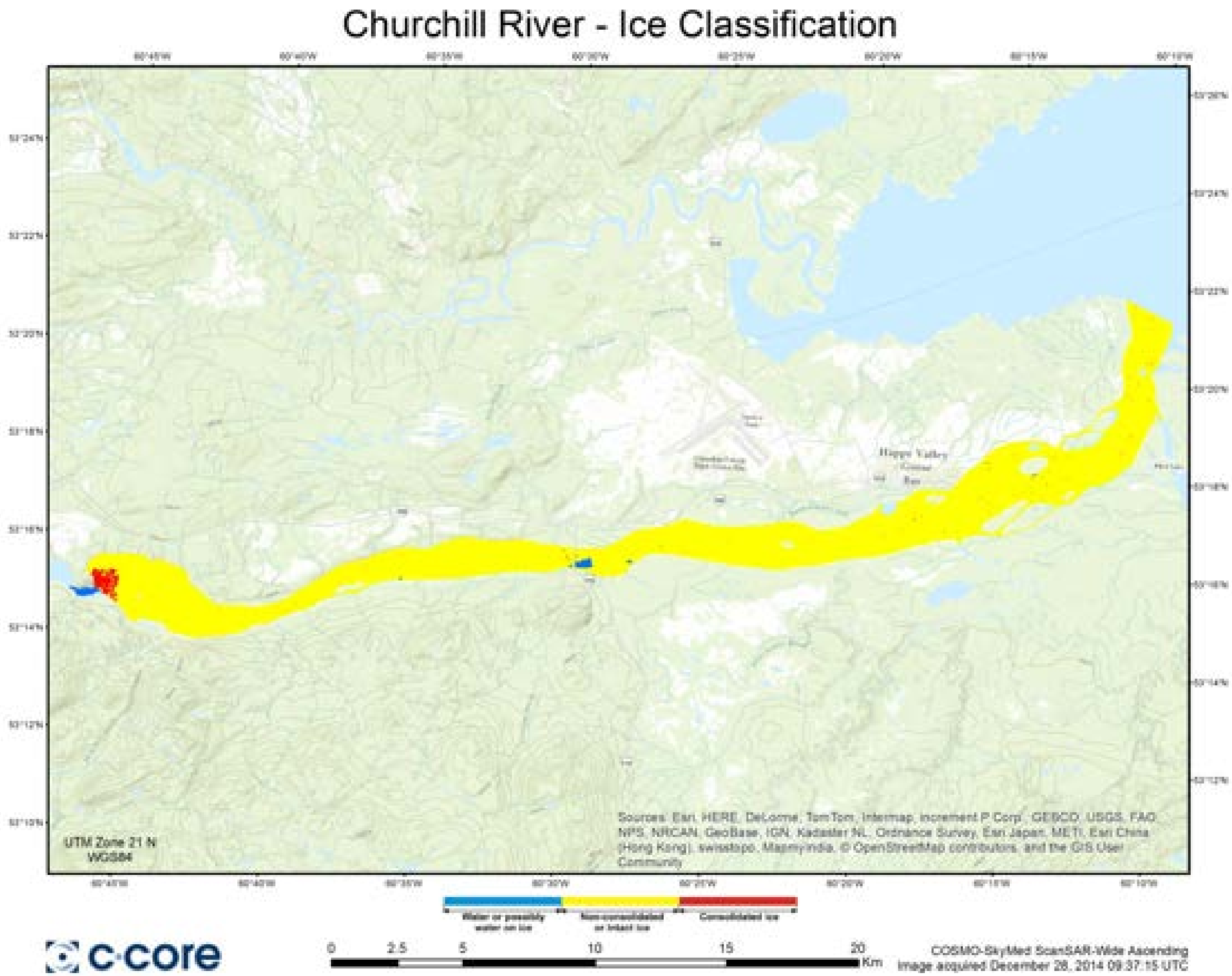

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 23, 2014 09:43:17 UTC

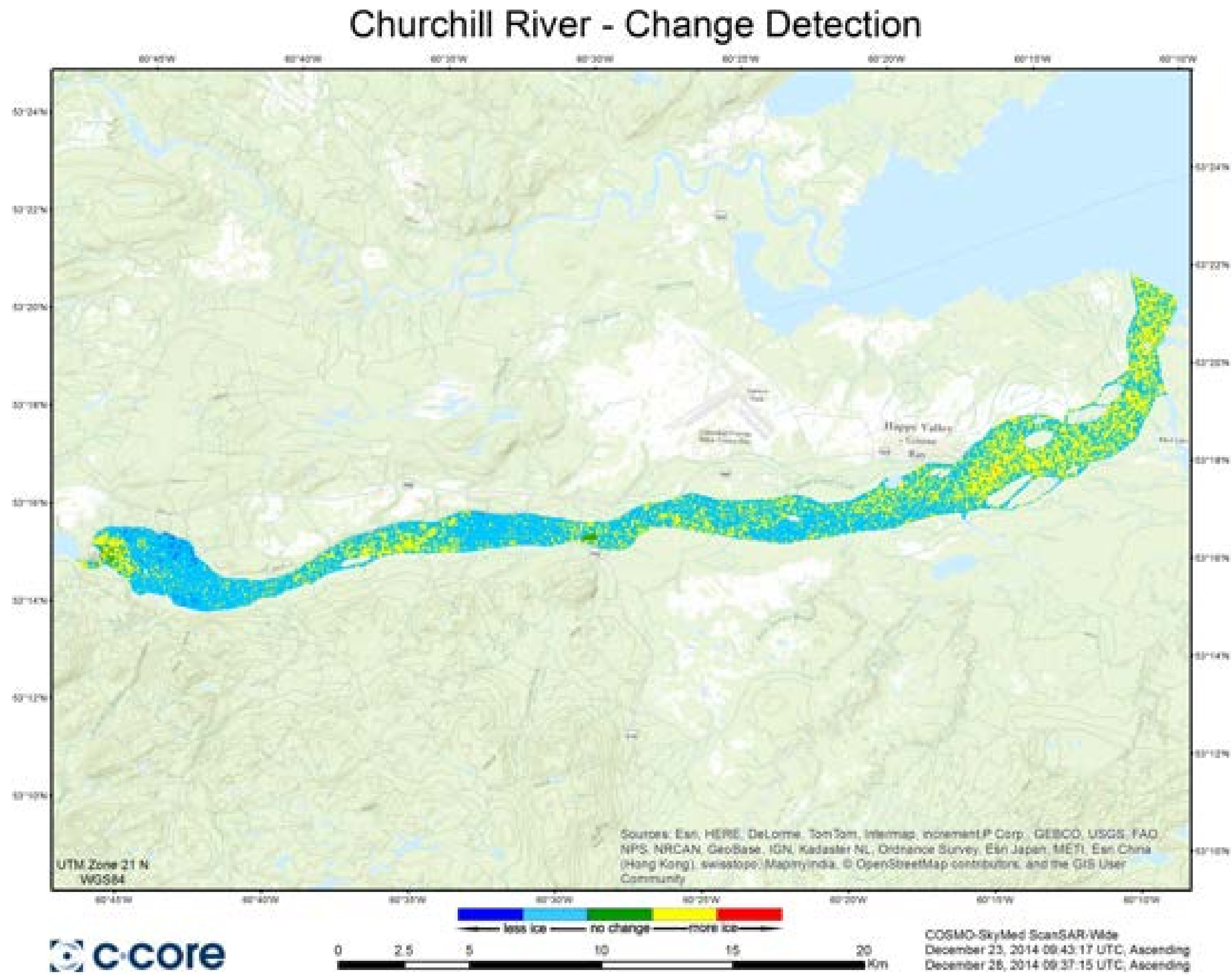
Churchill River - Ice Classification



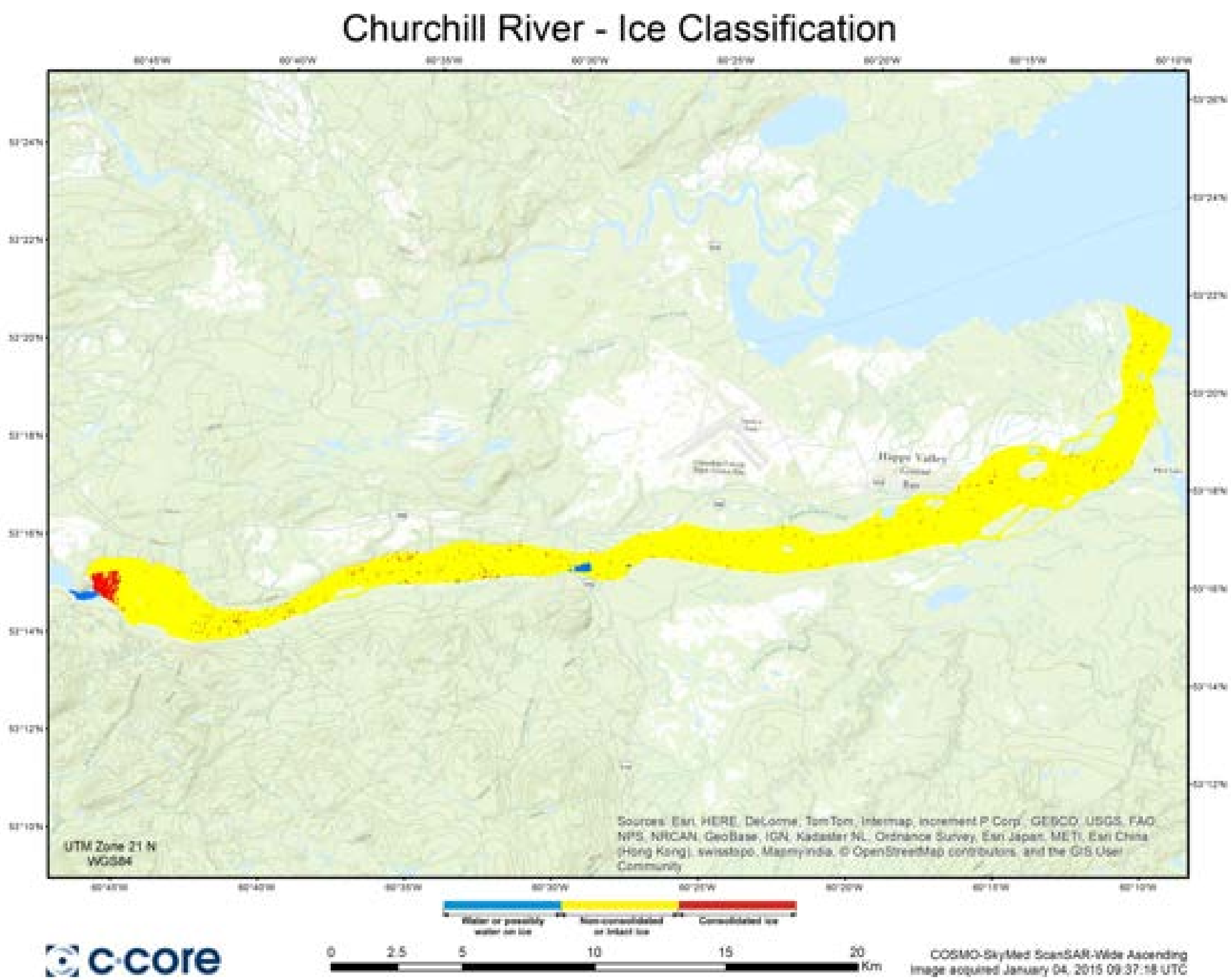

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
c·core
COSMO-SkyMed ScanSAR-Wide
December 19, 2014 09:37:20 UTC, Ascending
December 23, 2014 09:43:17 UTC, Ascending

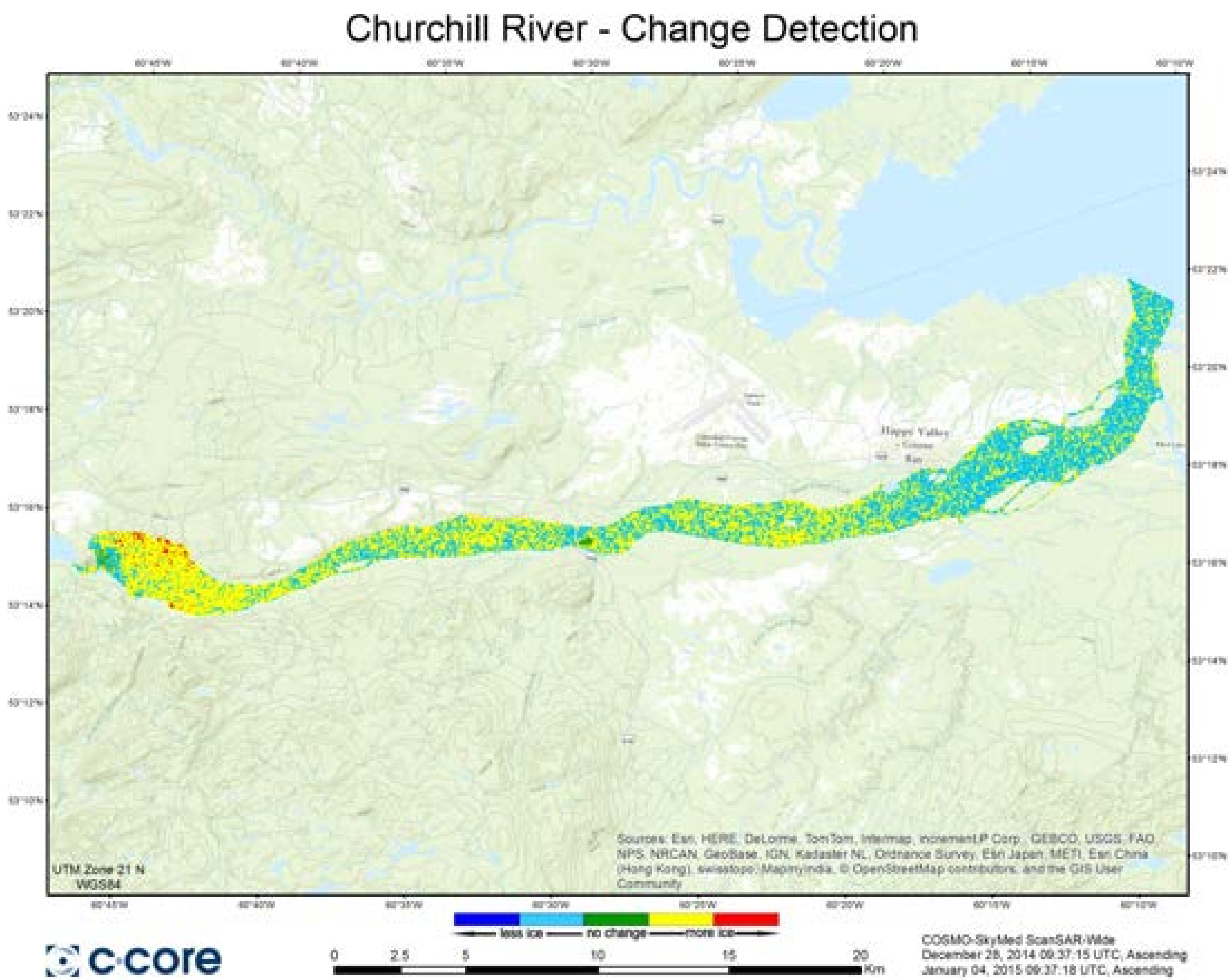

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 28, 2014 09:37:15 UTC

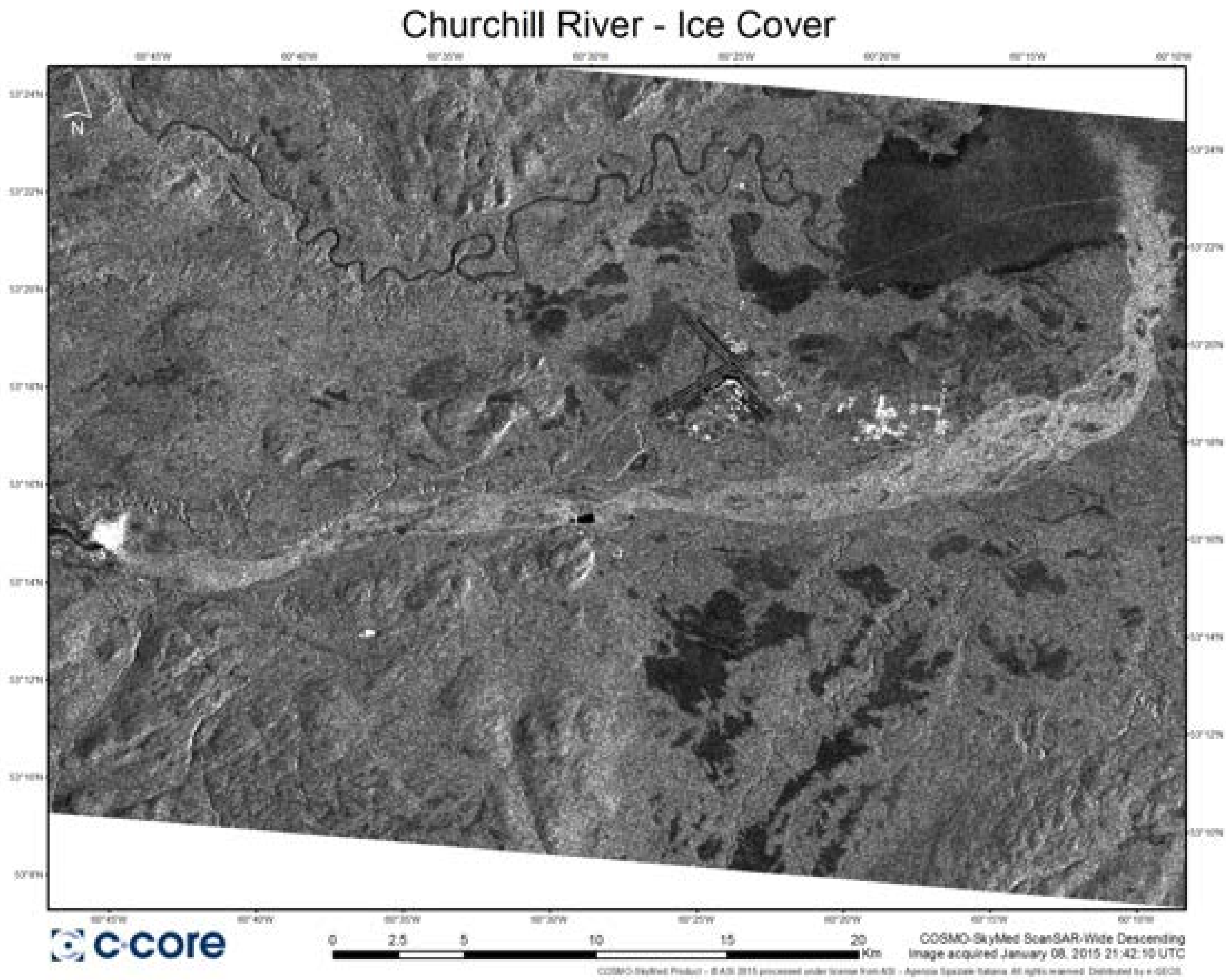

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired December 28, 2014 09:37:15 UTC

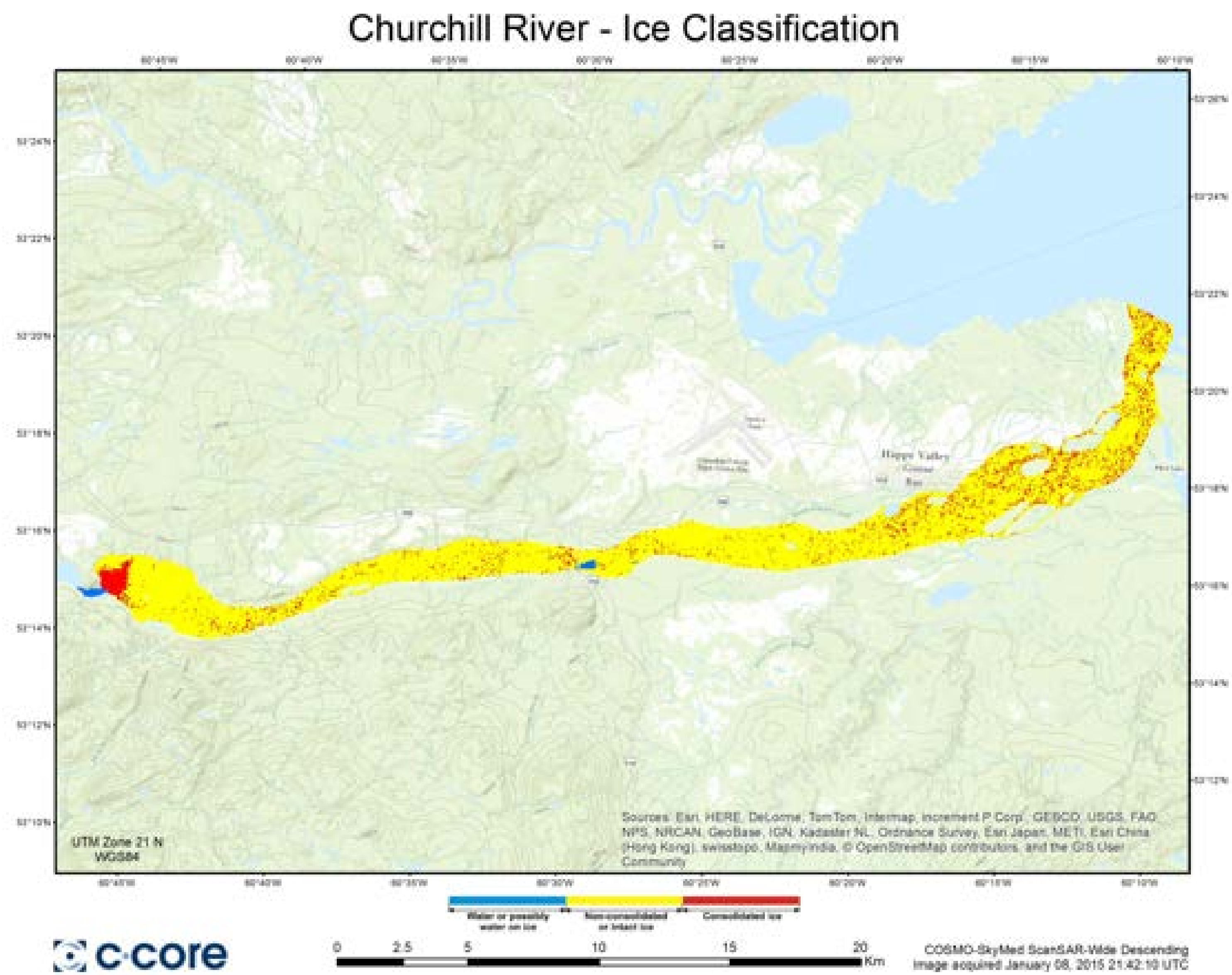

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
December 23, 2014 09:43:17 UTC, Ascending
December 28, 2014 09:37:15 UTC, Ascending

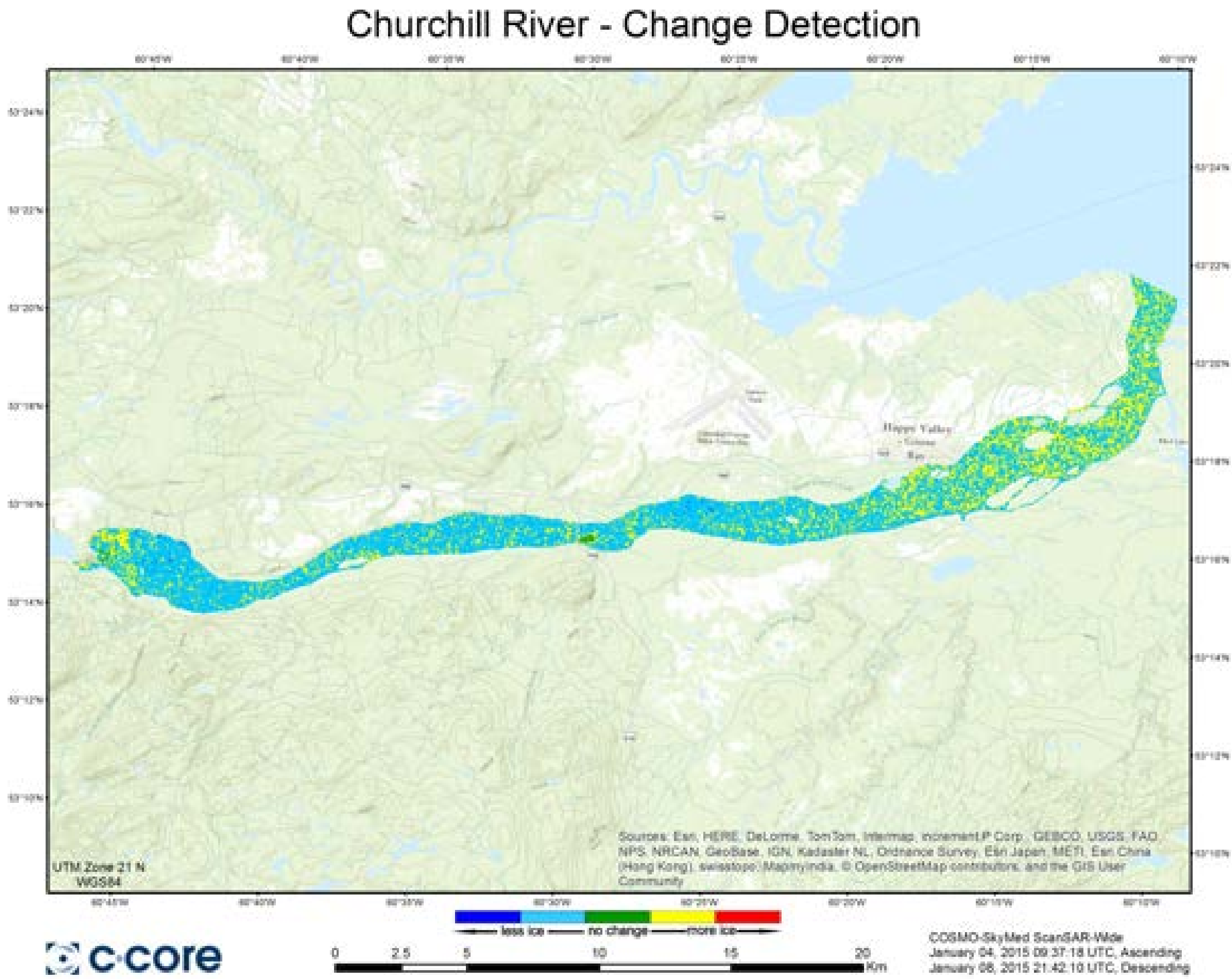

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 04, 2015 09:37:18 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 04, 2015 09:37:18 UTC

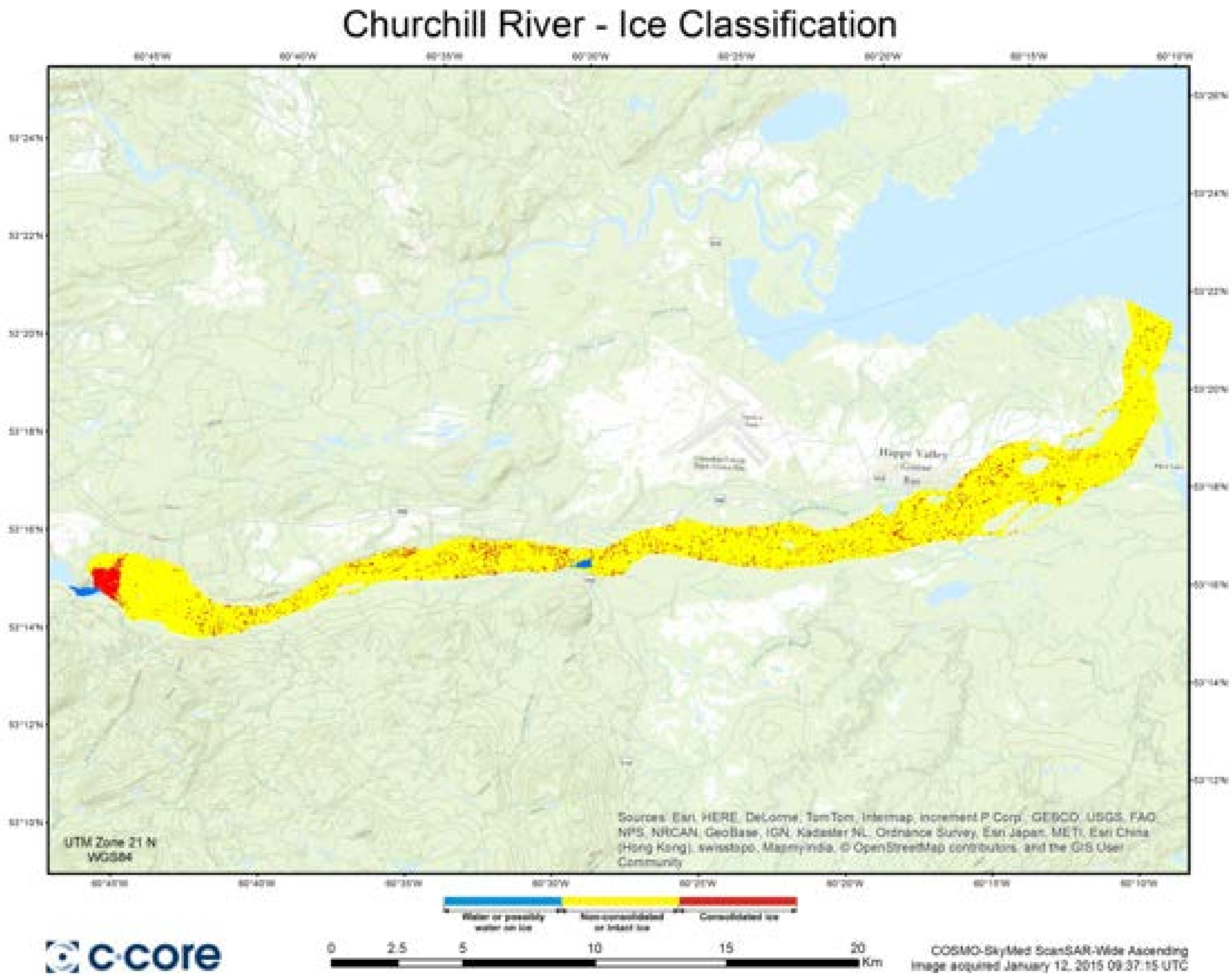

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
December 28, 2014 09:37:15 UTC, Ascending
January 04, 2015 09:37:18 UTC, Ascending

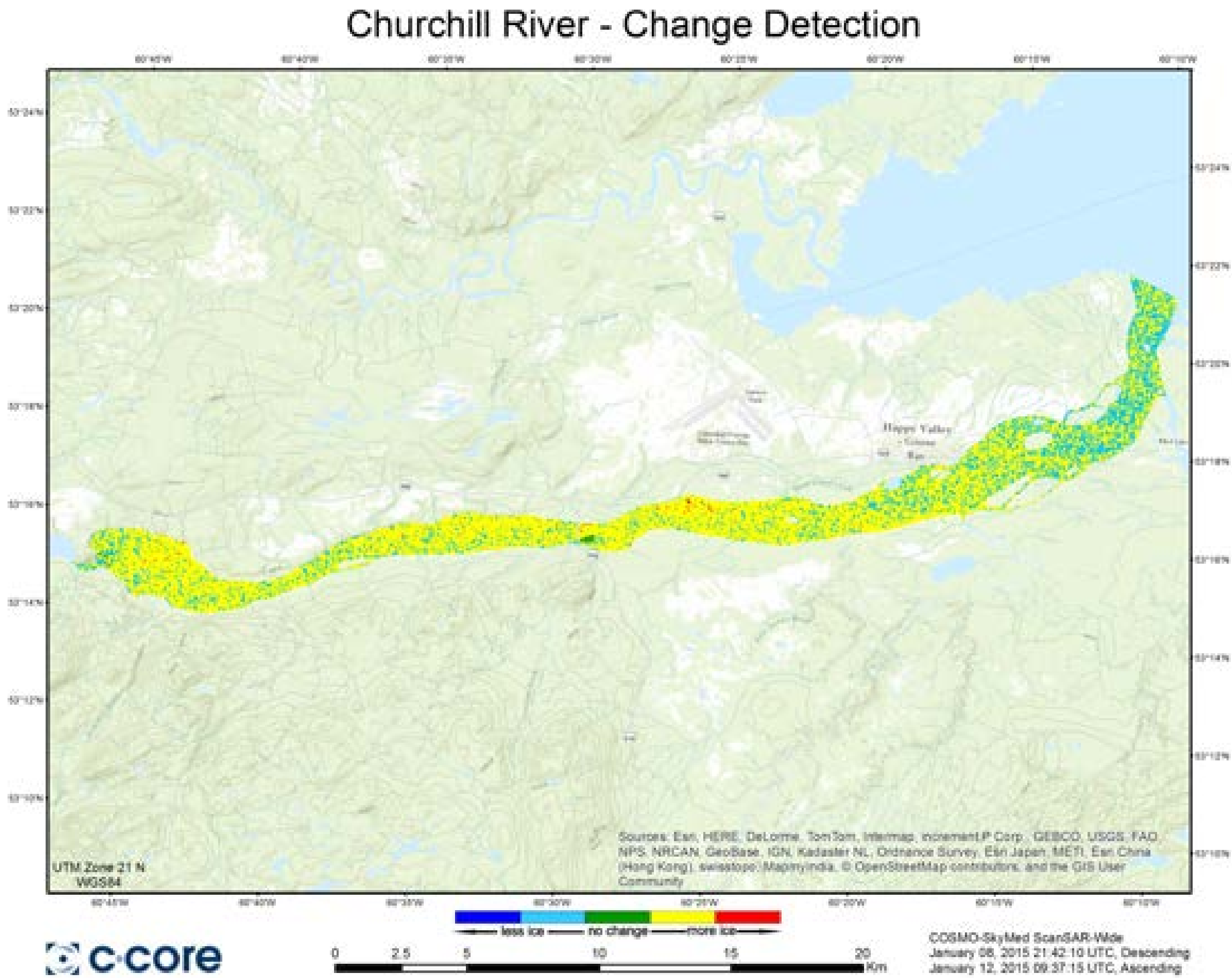

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired January 08, 2015 21:42:10 UTC


Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired January 08, 2015 21:42:10 UTC

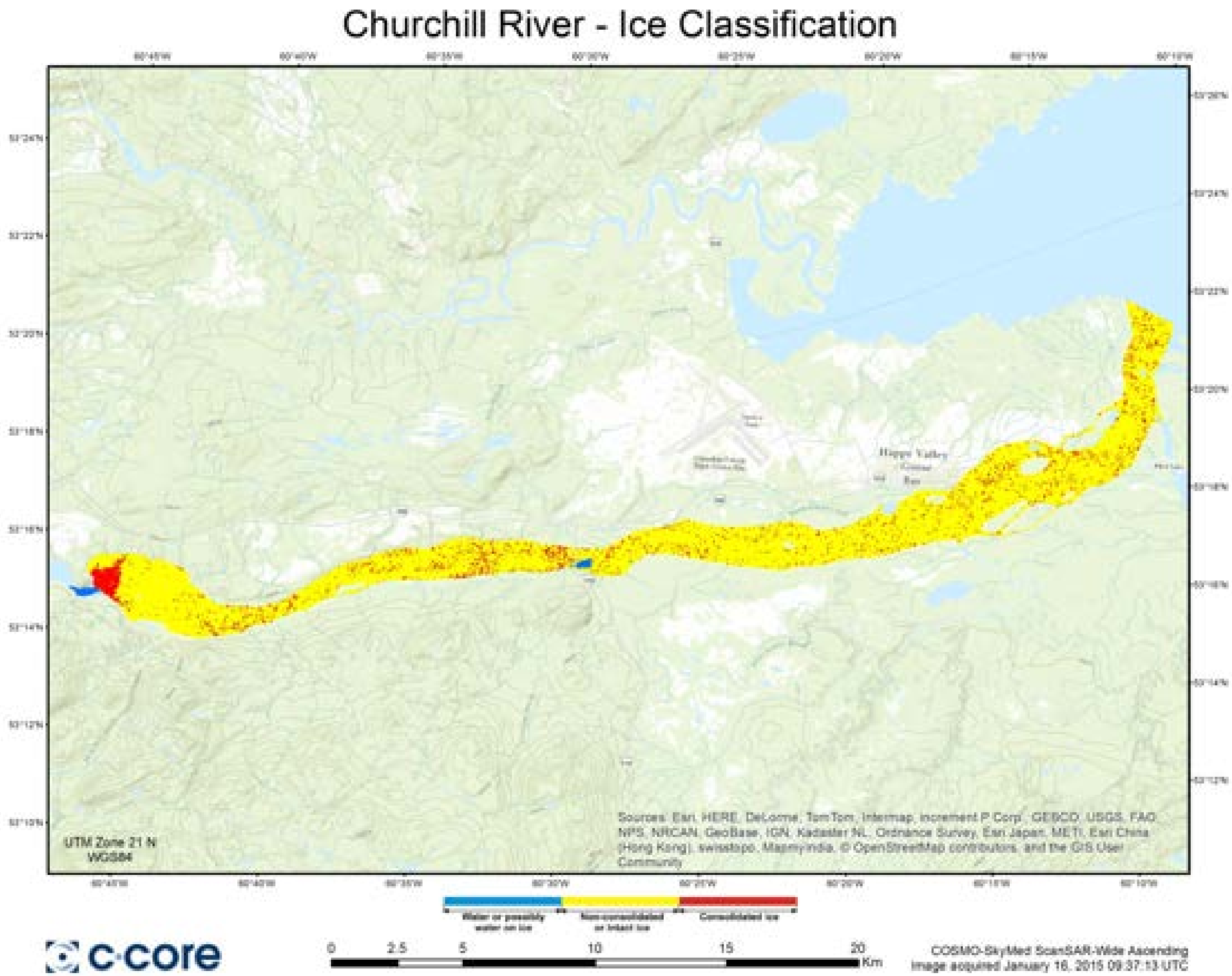

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
January 04, 2015 09:37:18 UTC, Ascending
January 08, 2015 21:42:10 UTC, Descending

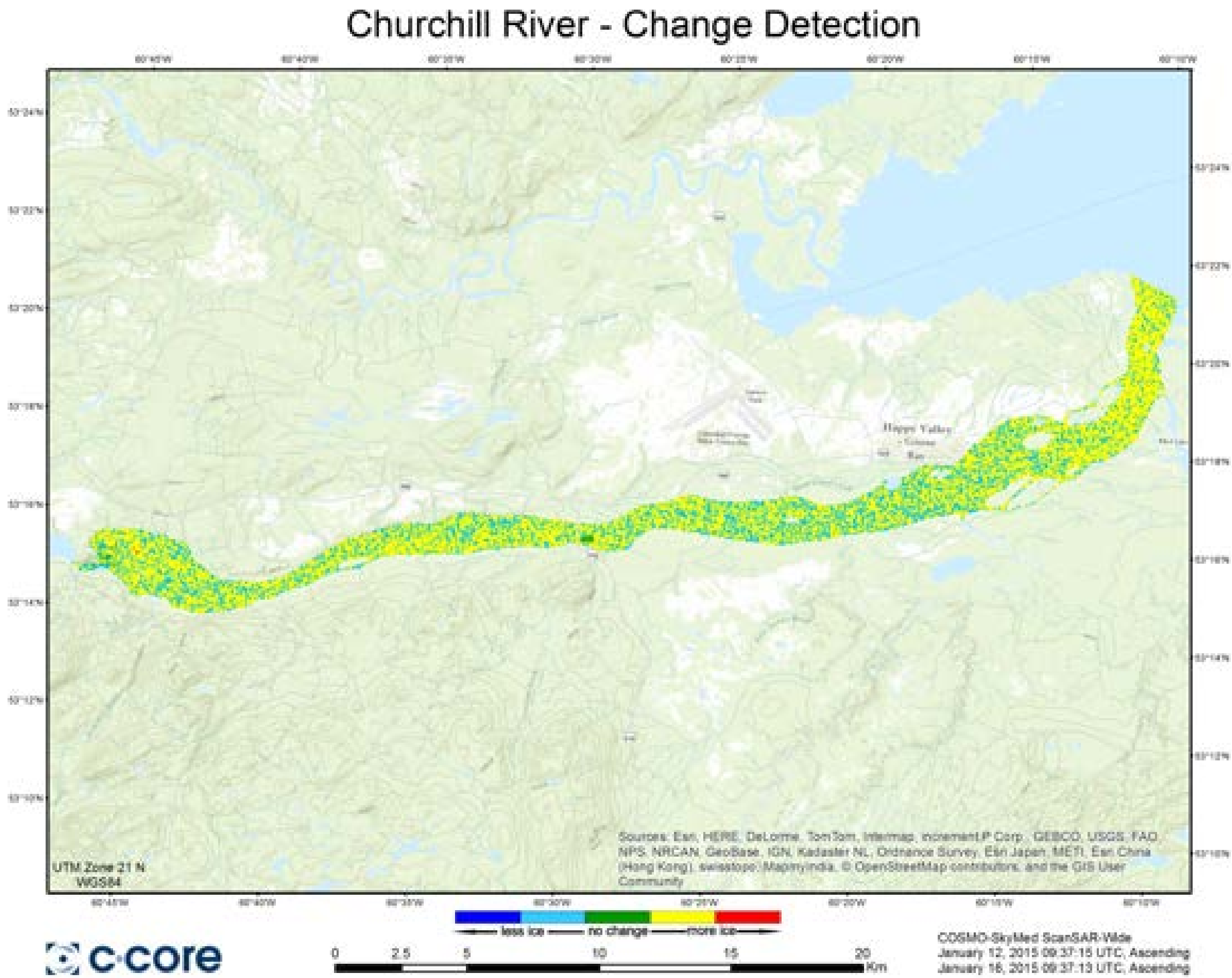

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 12, 2015 09:37:15 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 12, 2015 09:37:15 UTC

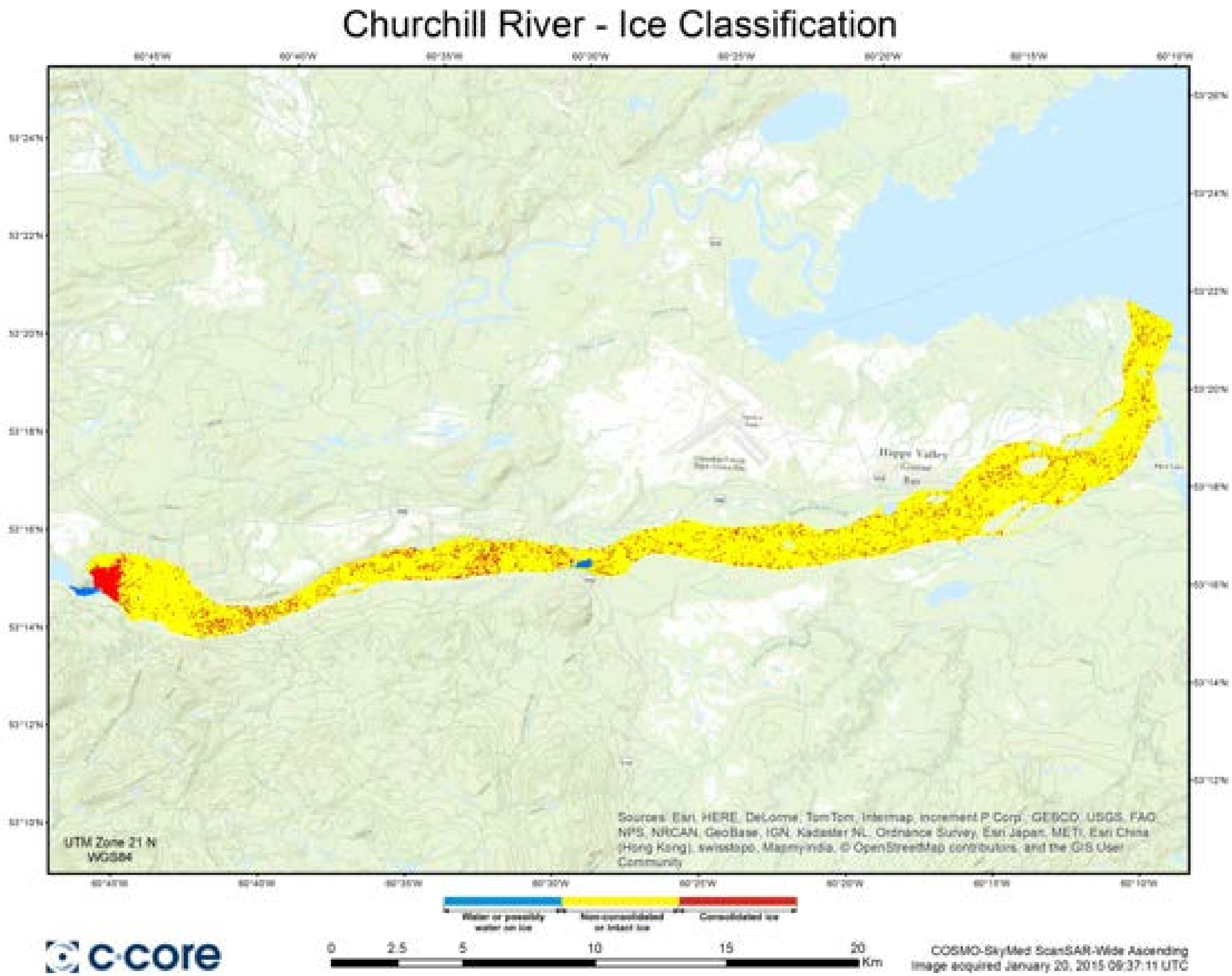

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
January 08, 2015 21:42:10 UTC, Descending
January 12, 2015 09:37:15 UTC, Ascending

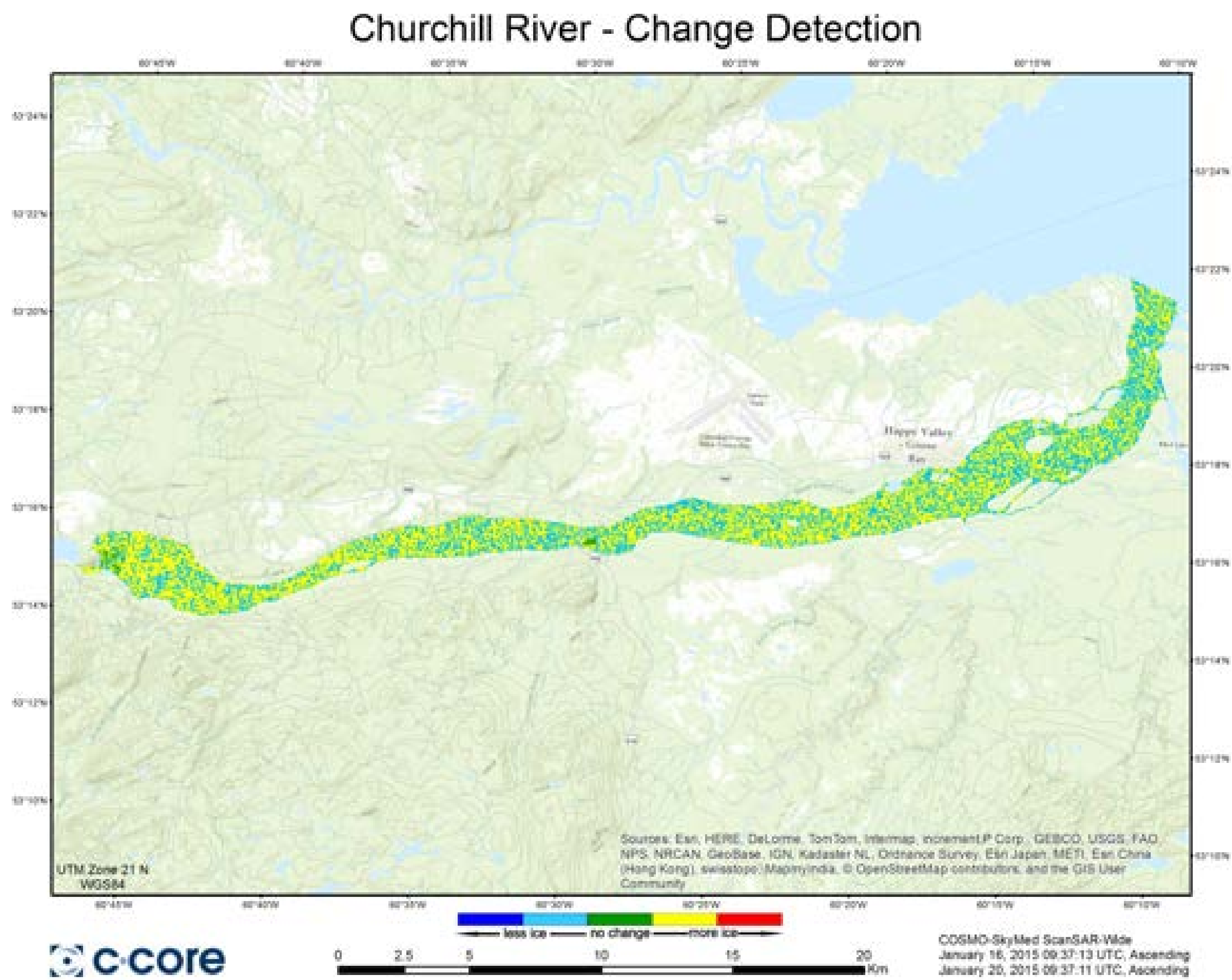

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
c-core
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 16, 2015 09:37:13 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 16, 2015 09:37:13 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
January 12, 2015 09:37:15 UTC, Ascending
January 16, 2015 09:37:13 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 20, 2015 09:37:11 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 20, 2015 09:37:11 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
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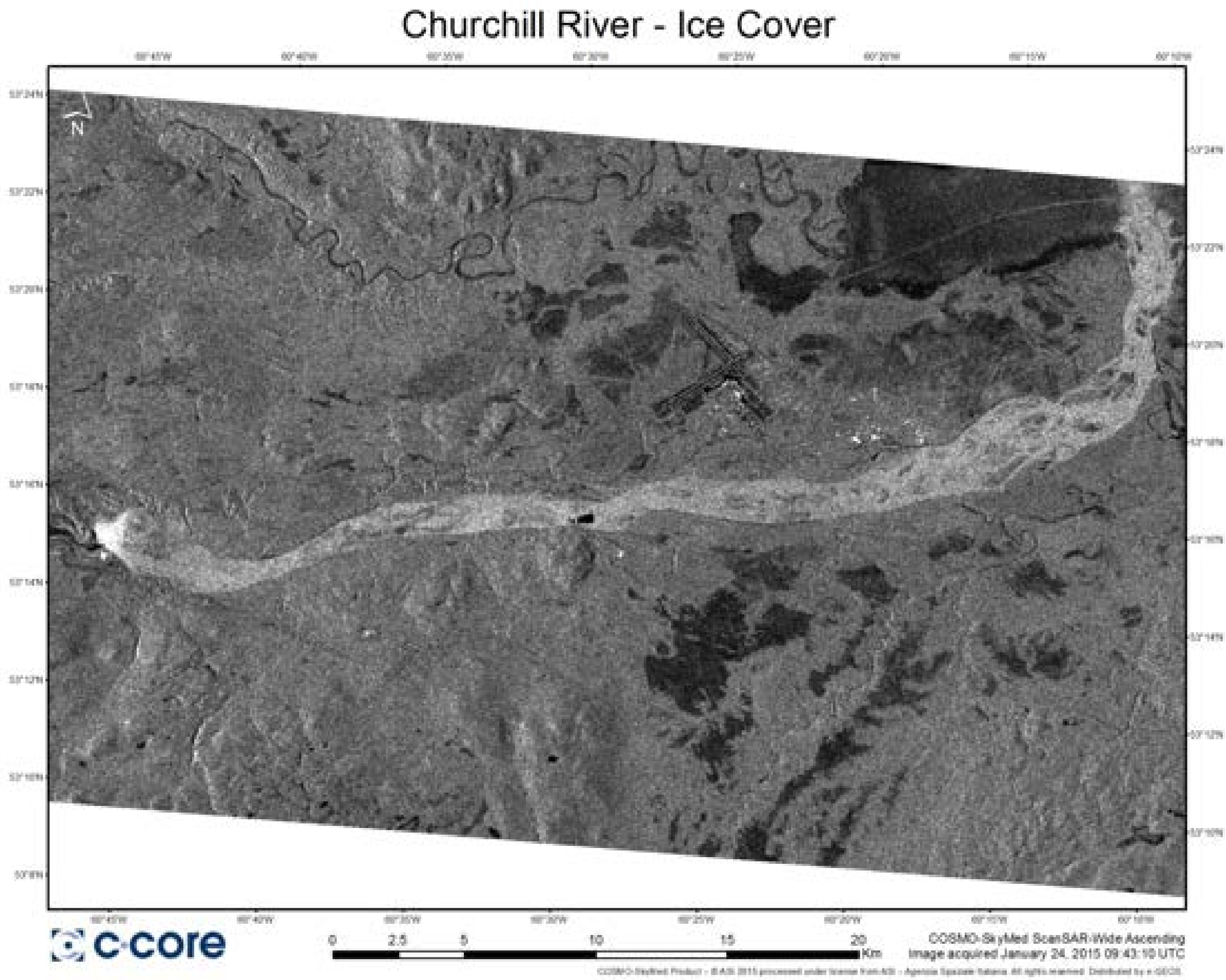
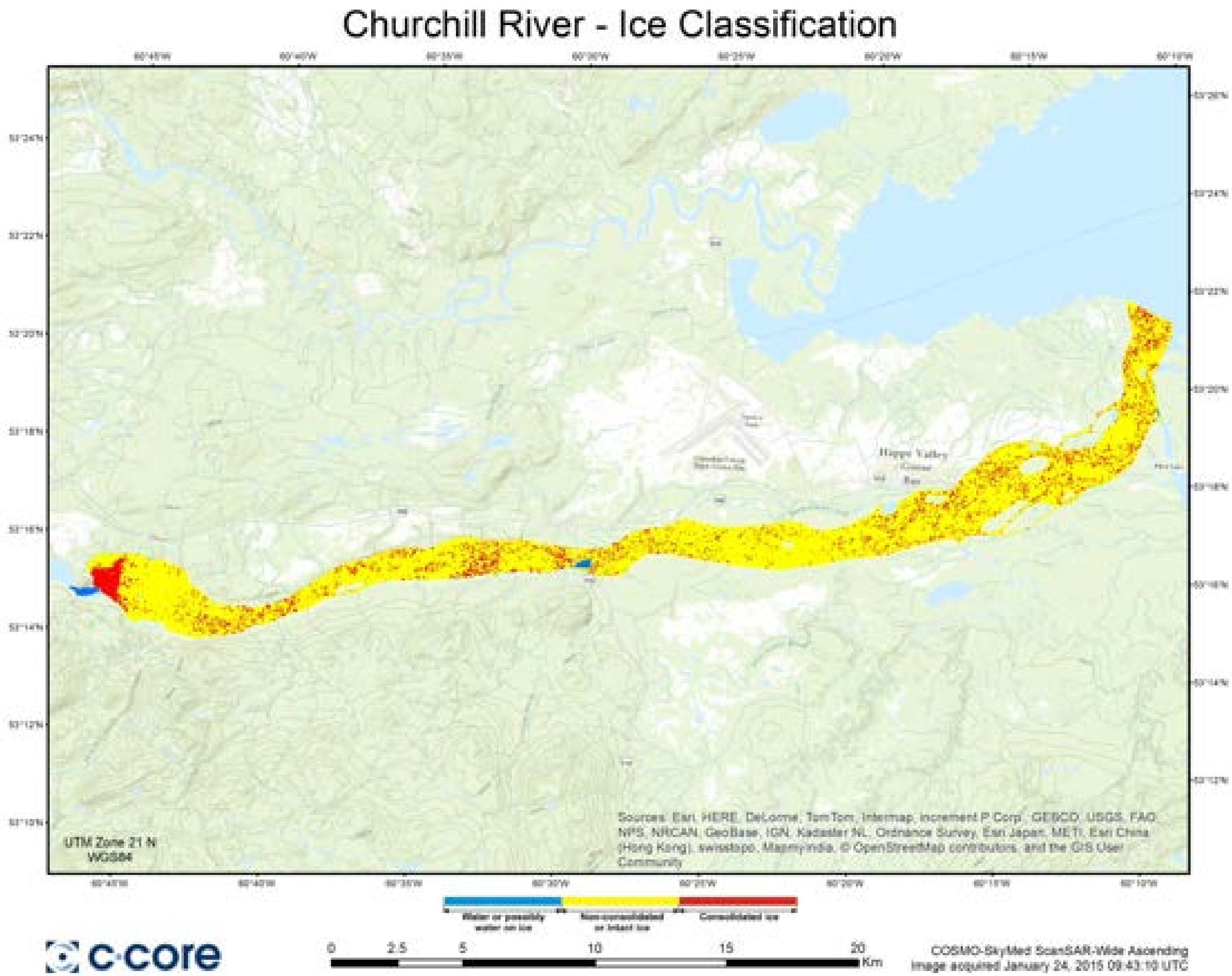
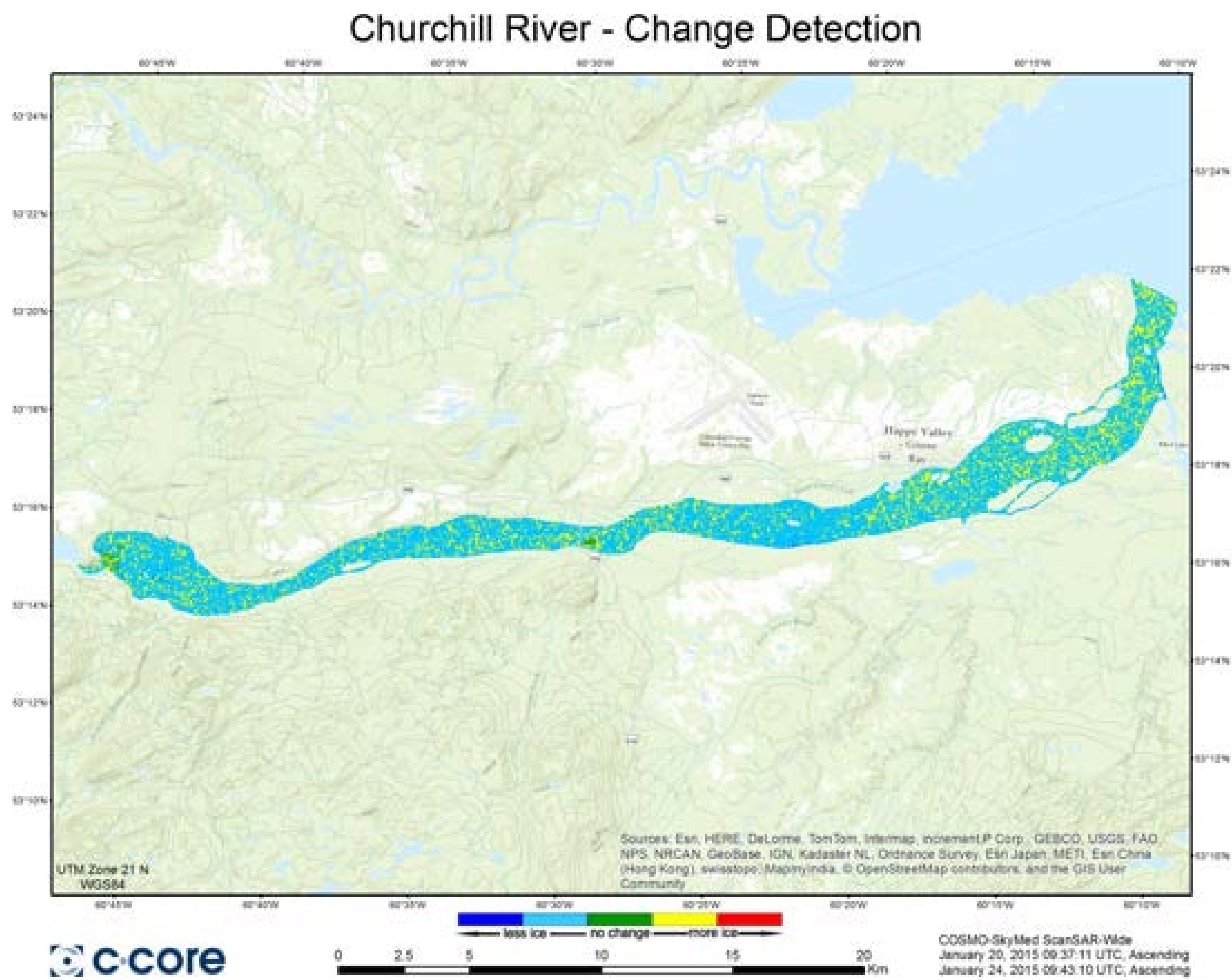
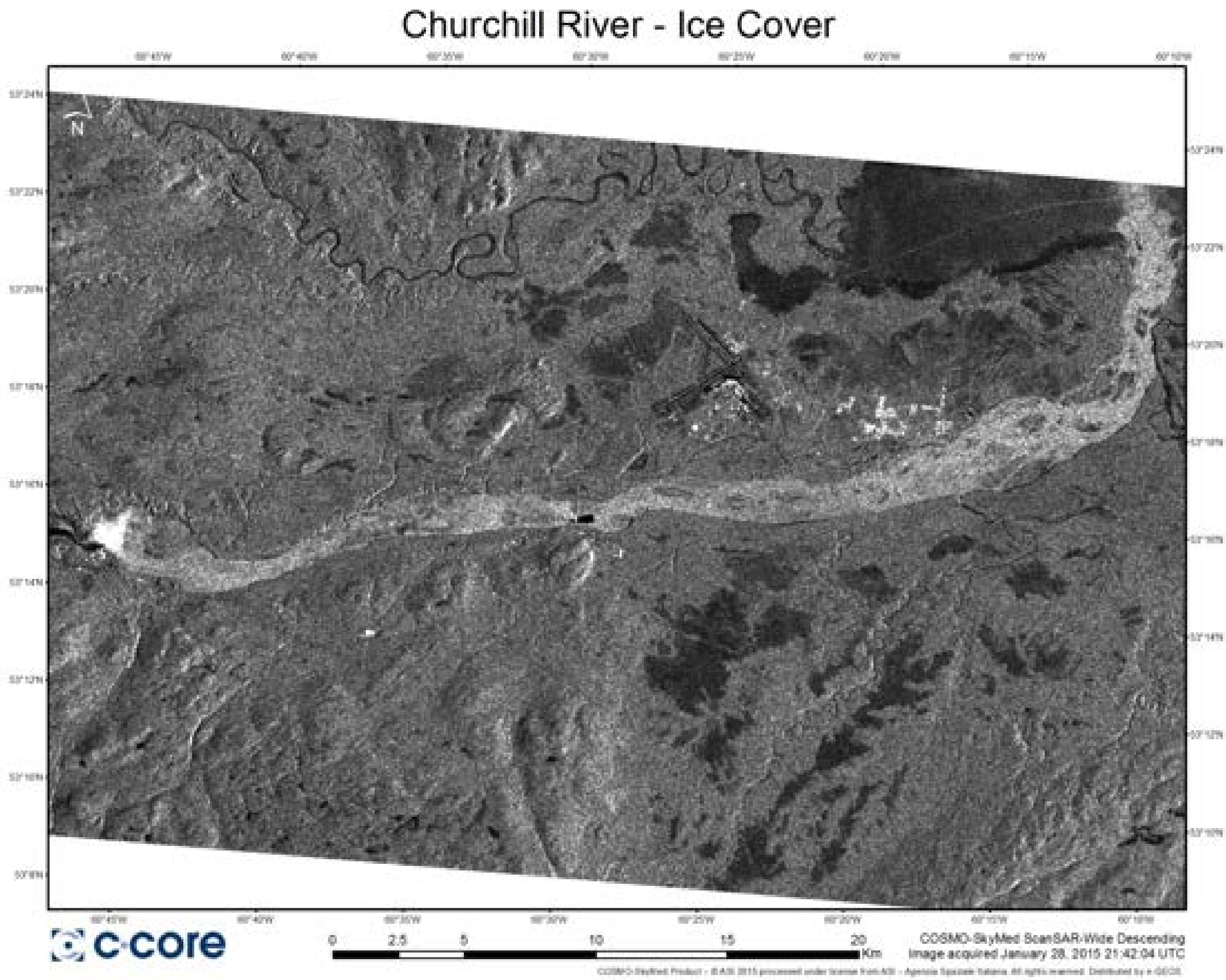
20
Km
COSMO-SkyMed ScanSAR-Wide
January 16, 2015 09:37:13 UTC, Ascending
January 20, 2015 09:37:11 UTC, Ascending

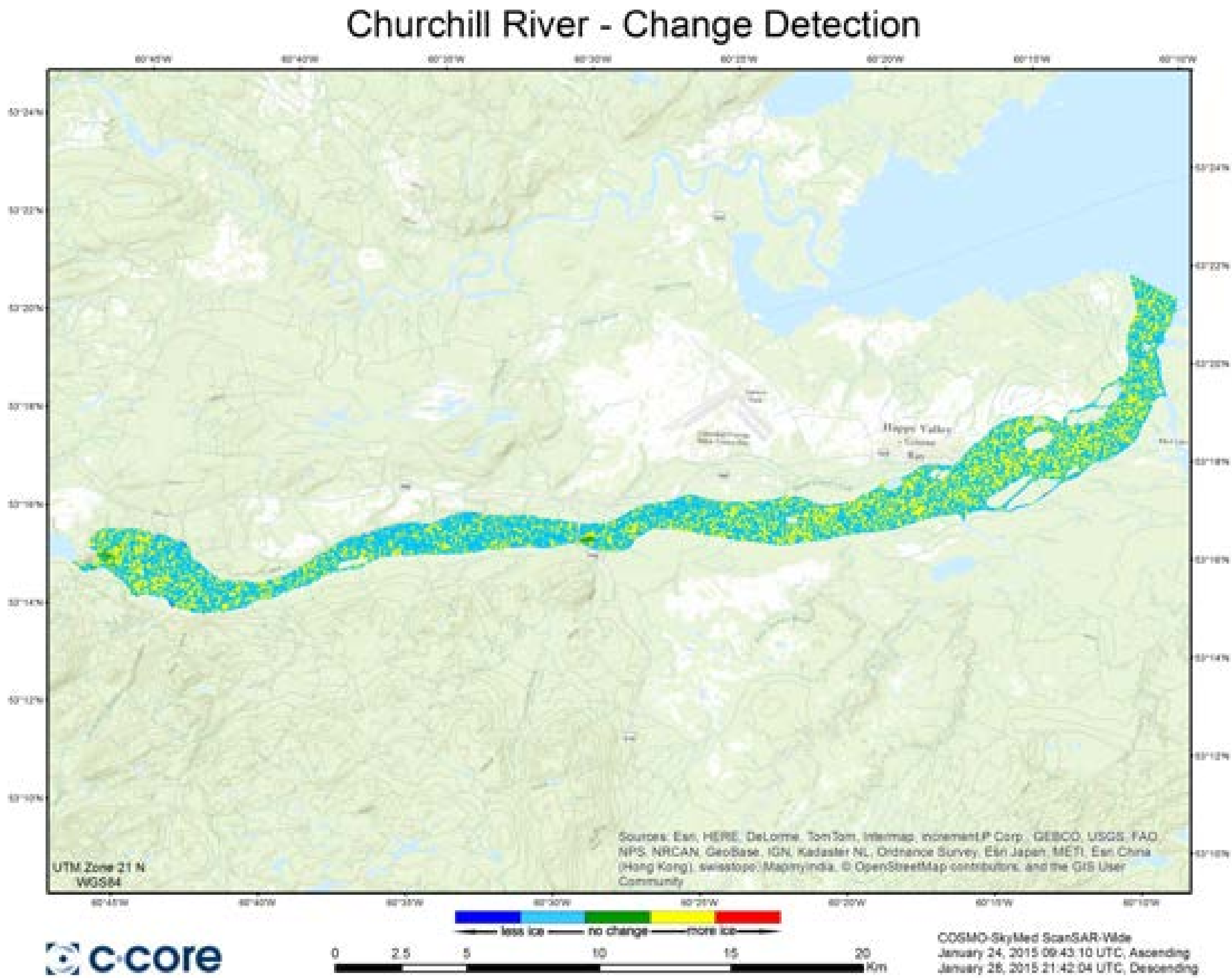

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 24, 2015 09:43:10 UTC

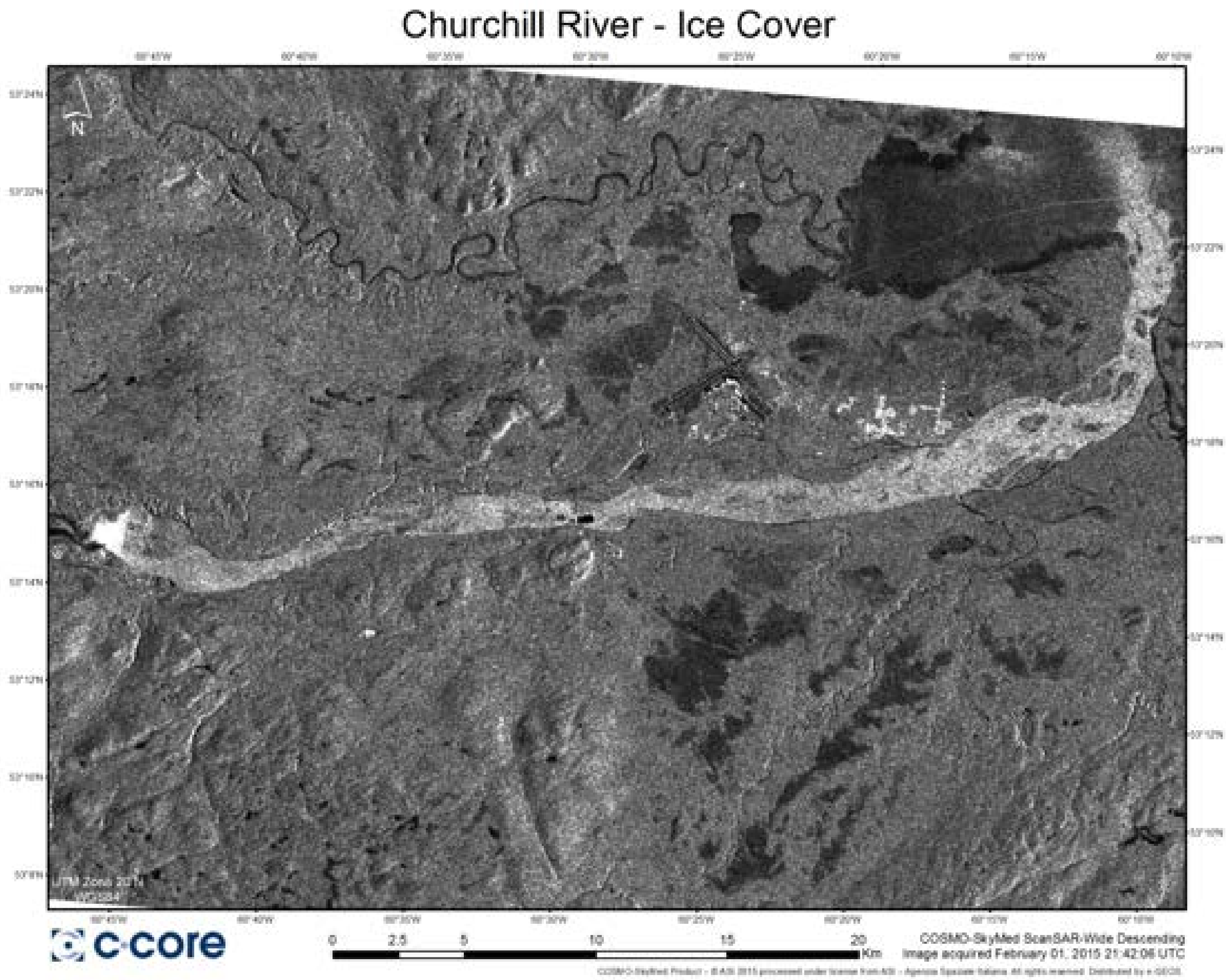


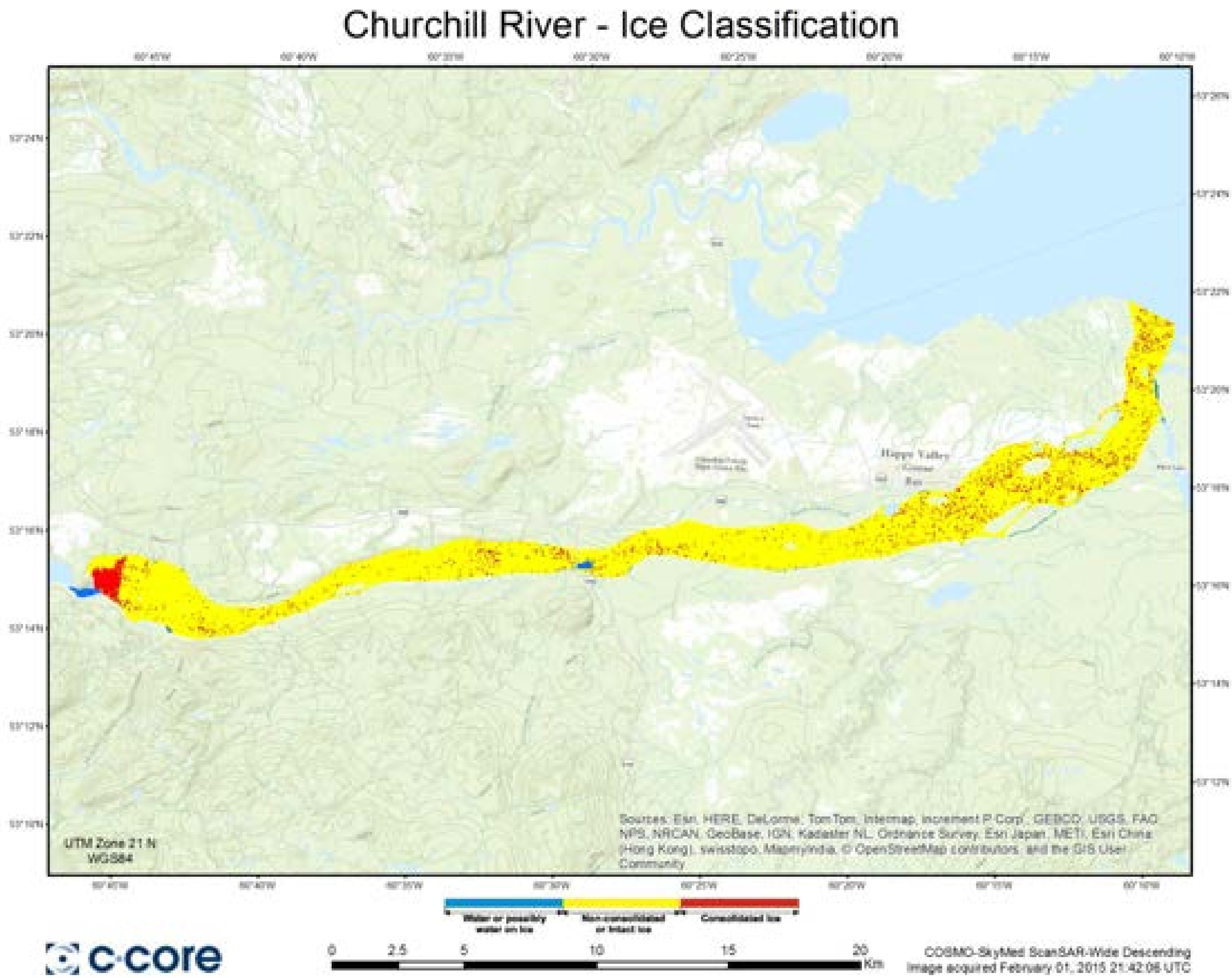
Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired January 24, 2015 09:43:10 UTC

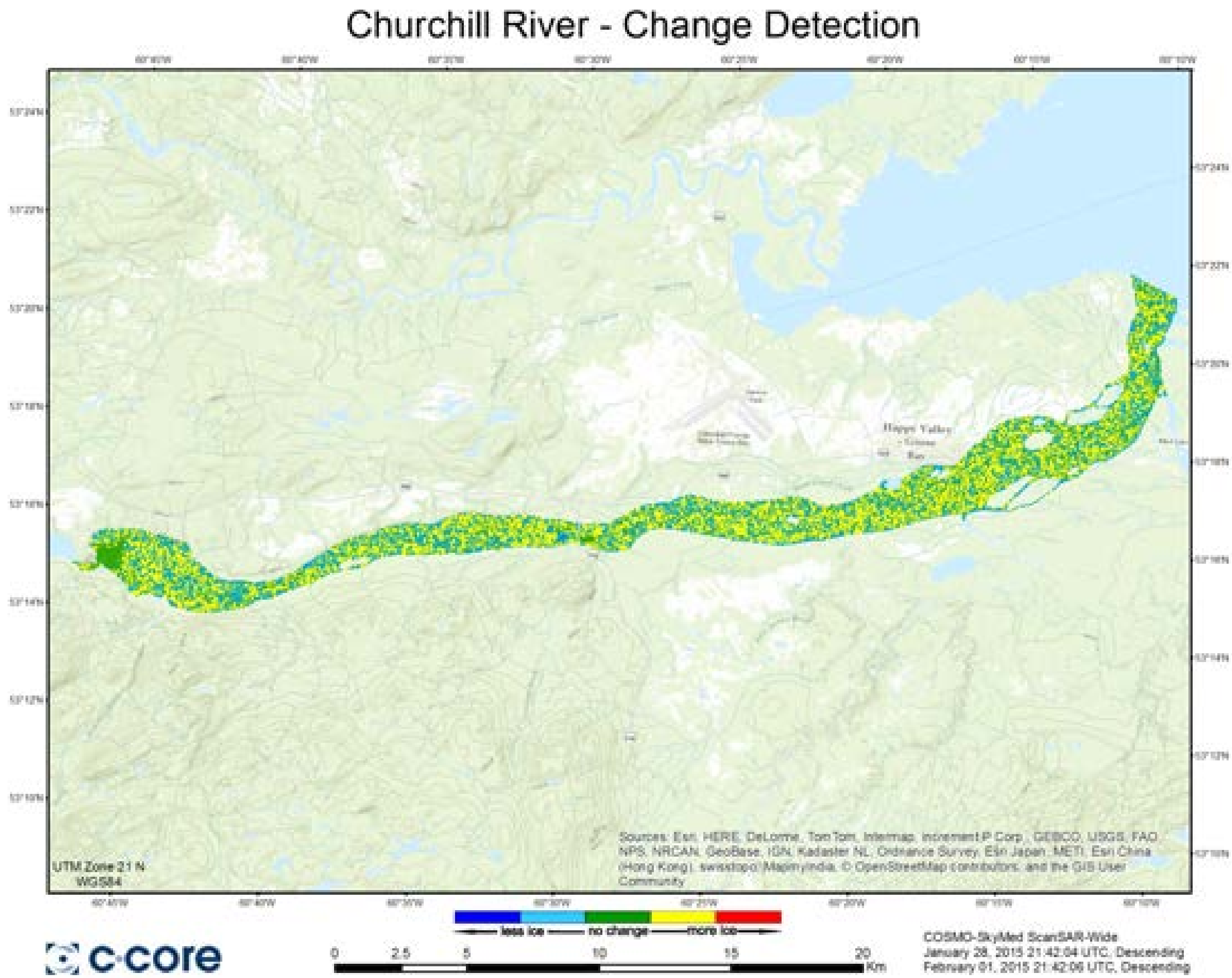

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Happy Valley - Goose Bay
less ice
no change
more ice
0
2.5
5
10
15
20
Km
c-core
COSMO-SkyMed ScanSAR-Wide
January 20, 2015 09:37:11 UTC, Ascending
January 24, 2015 09:43:10 UTC, Ascending


Churchill River - Ice Cover
N
c-core
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired January 28, 2015 21:42:04 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
January 24, 2015 09:43:10 UTC, Ascending
January 28, 2015 21:42:04 UTC, Descending


Churchill River - Ice Cover
N
UTM Zone 20N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired February 01, 2015 21:42:06 UTC


Churchill River - Ice Classification
Happy Valley
Goose
Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired February 01, 2015 21:42:06 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
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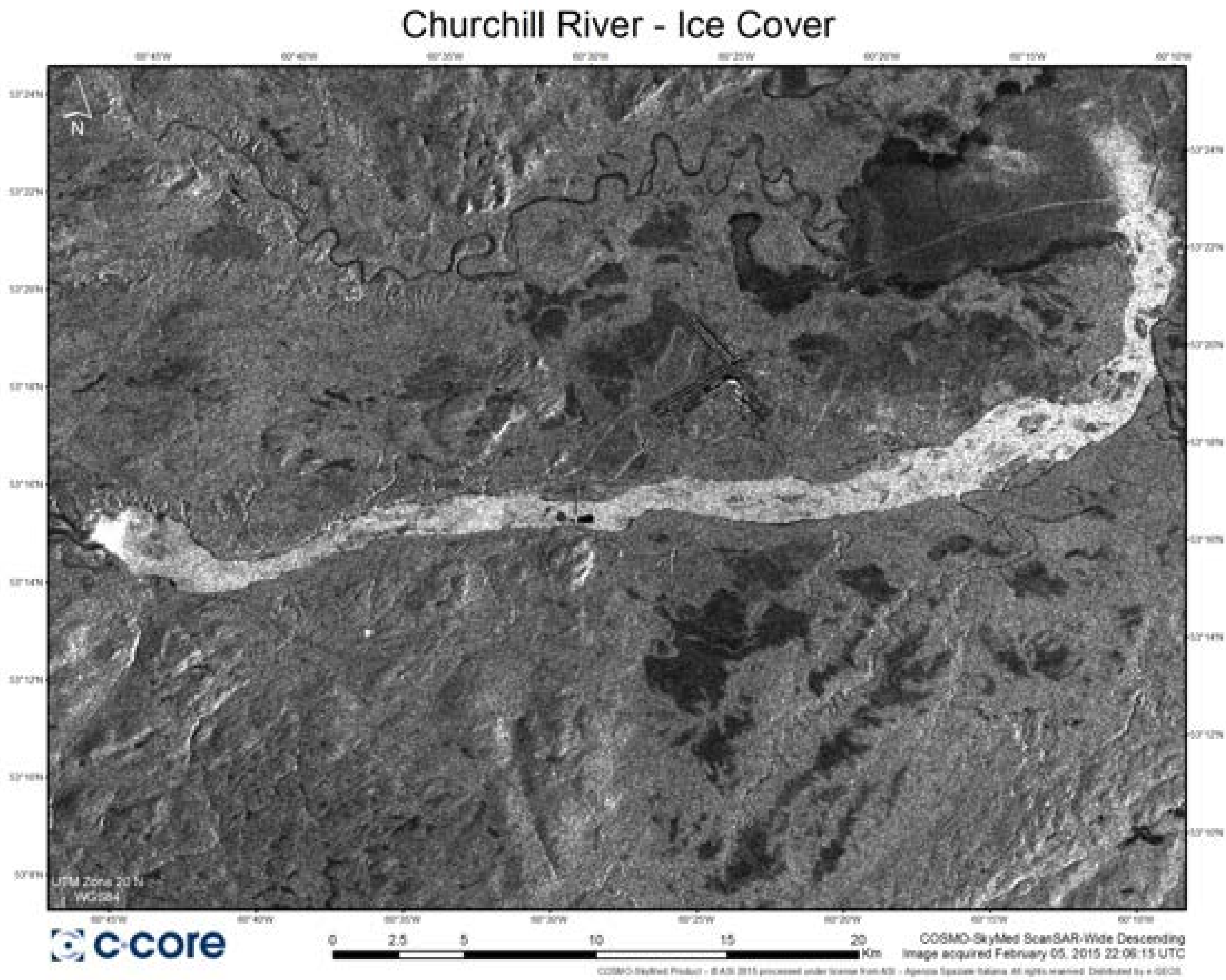
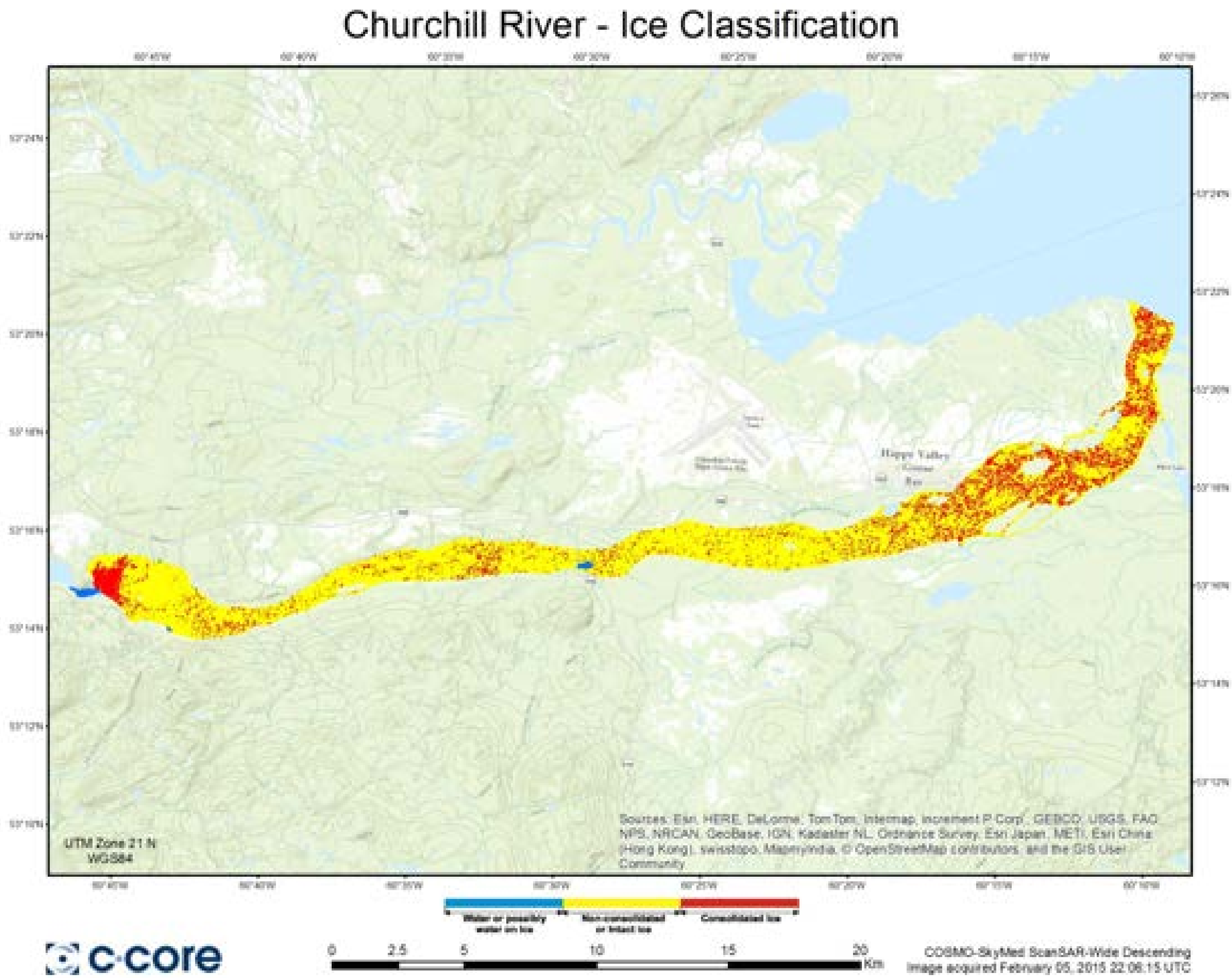
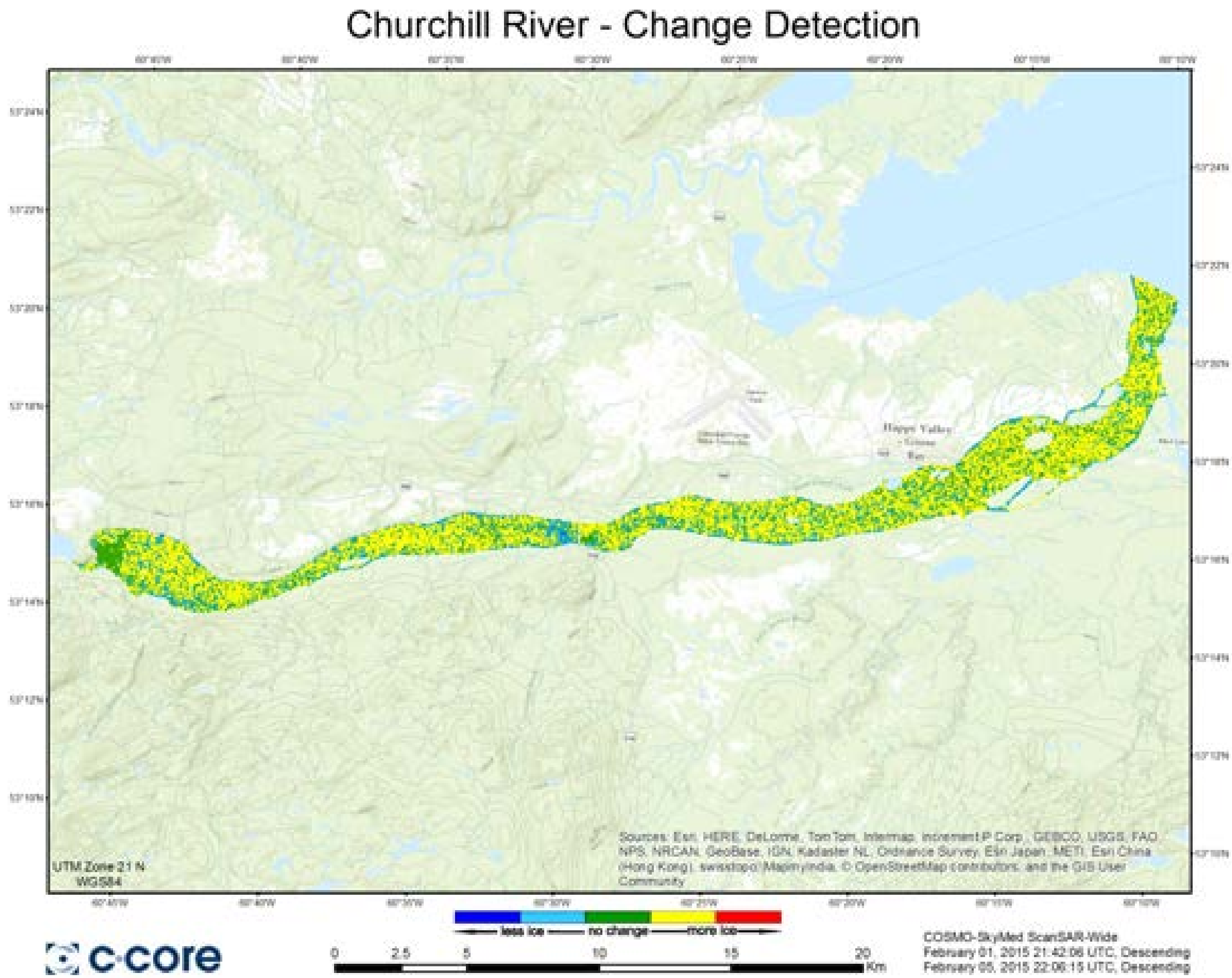
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
January 28, 2015 21:42:04 UTC, Descending
February 01, 2015 21:42:06 UTC, Descending


Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired February 05, 2015 22:06:15 UTC


Churchill River - Ice Classification
Happy Valley
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
c·core
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired February 05, 2015 22:06:15 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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2.5
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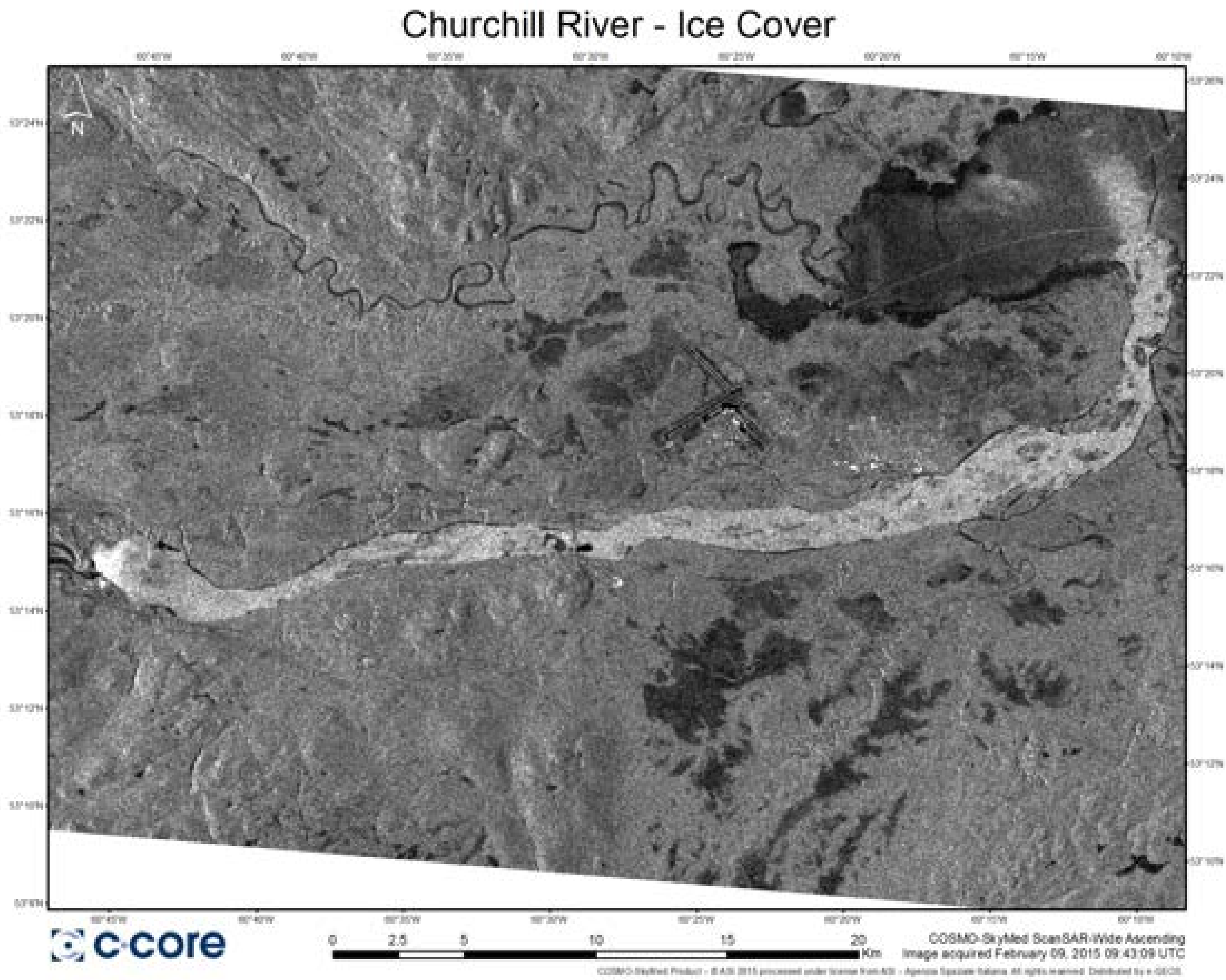
Km
c-core
COSMO-SkyMed ScanSAR-Wide
February 01, 2015 21:42:06 UTC, Descending
February 05, 2015 22:06:15 UTC, Descending


Churchill River - Ice Cover
N
c·core
0
2.5
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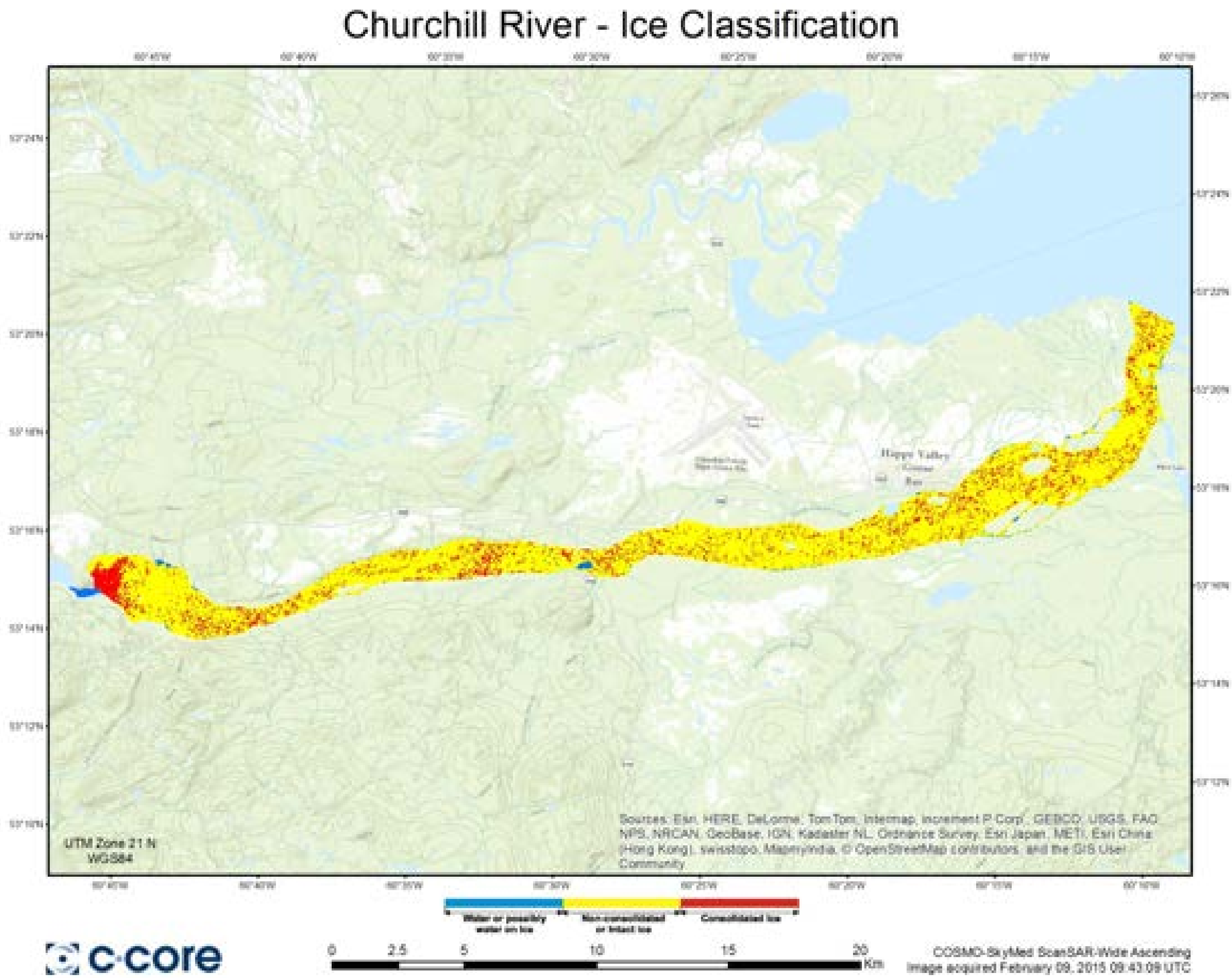
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 09, 2015 09:43:09 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
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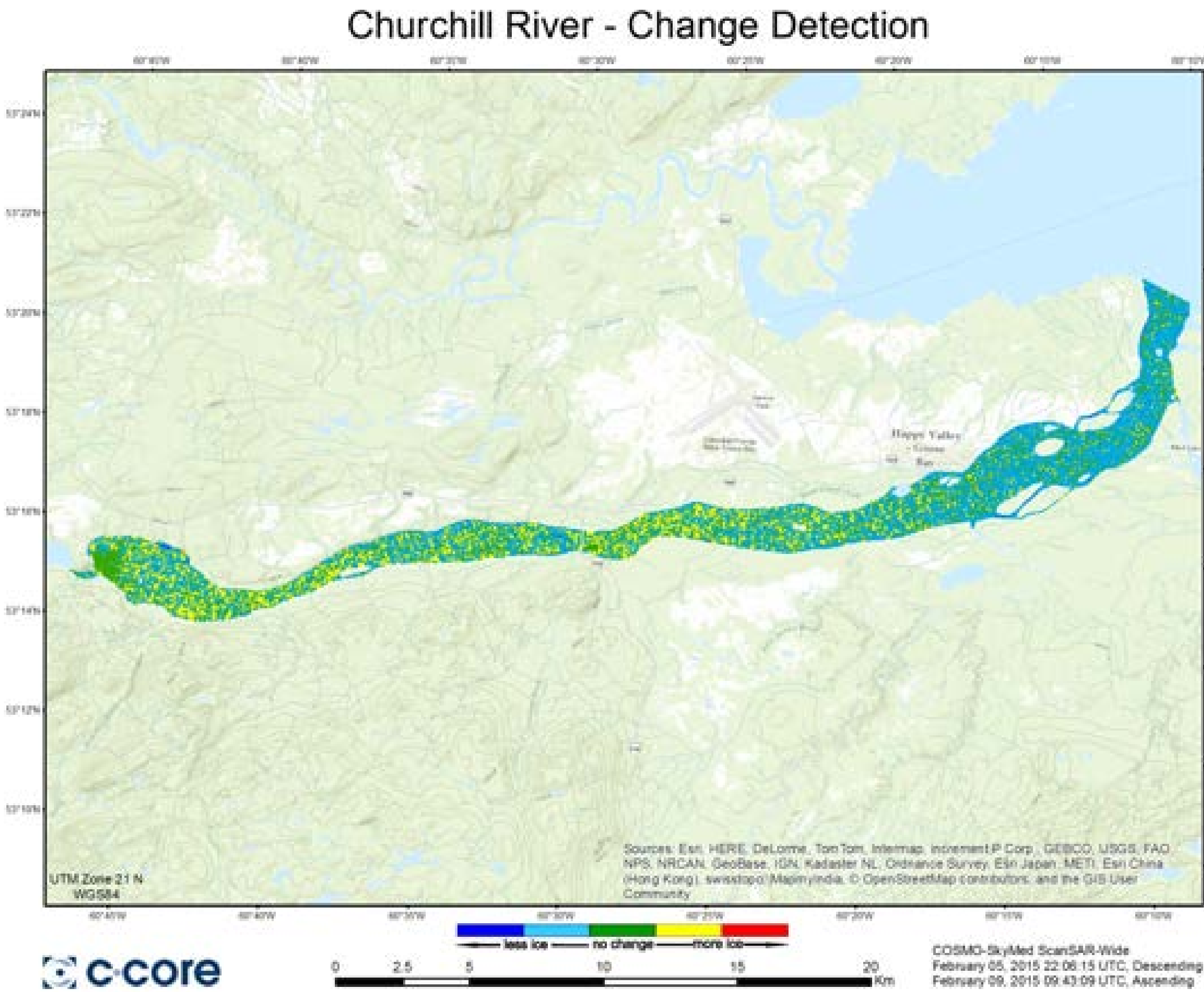
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 09, 2015 09:43:09 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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2.5
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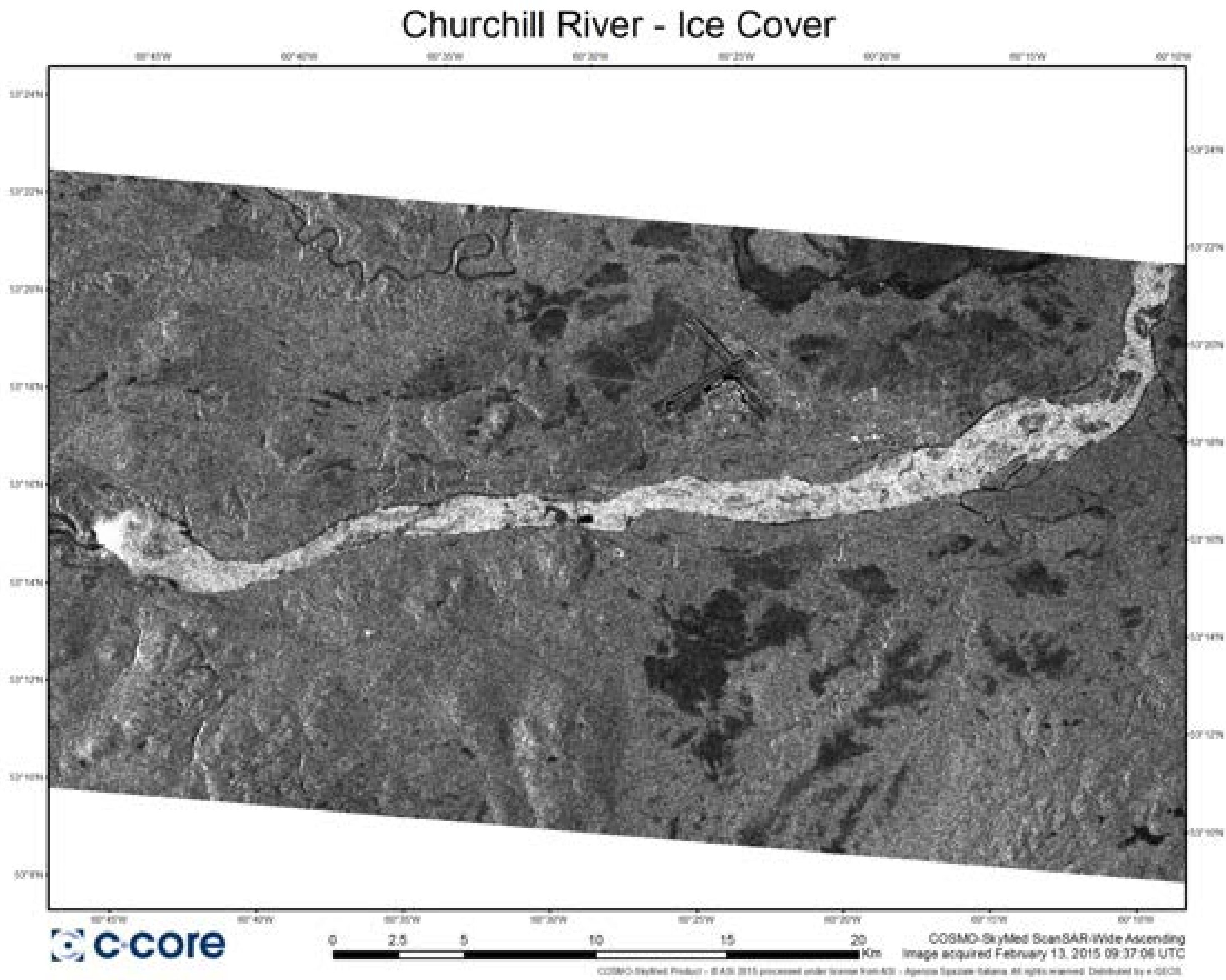
Km
c-core
COSMO-SkyMed ScanSAR-Wide
February 05, 2015 22:06:15 UTC, Descending
February 09, 2015 09:43:09 UTC, Ascending


Churchill River - Ice Cover
0
2.5
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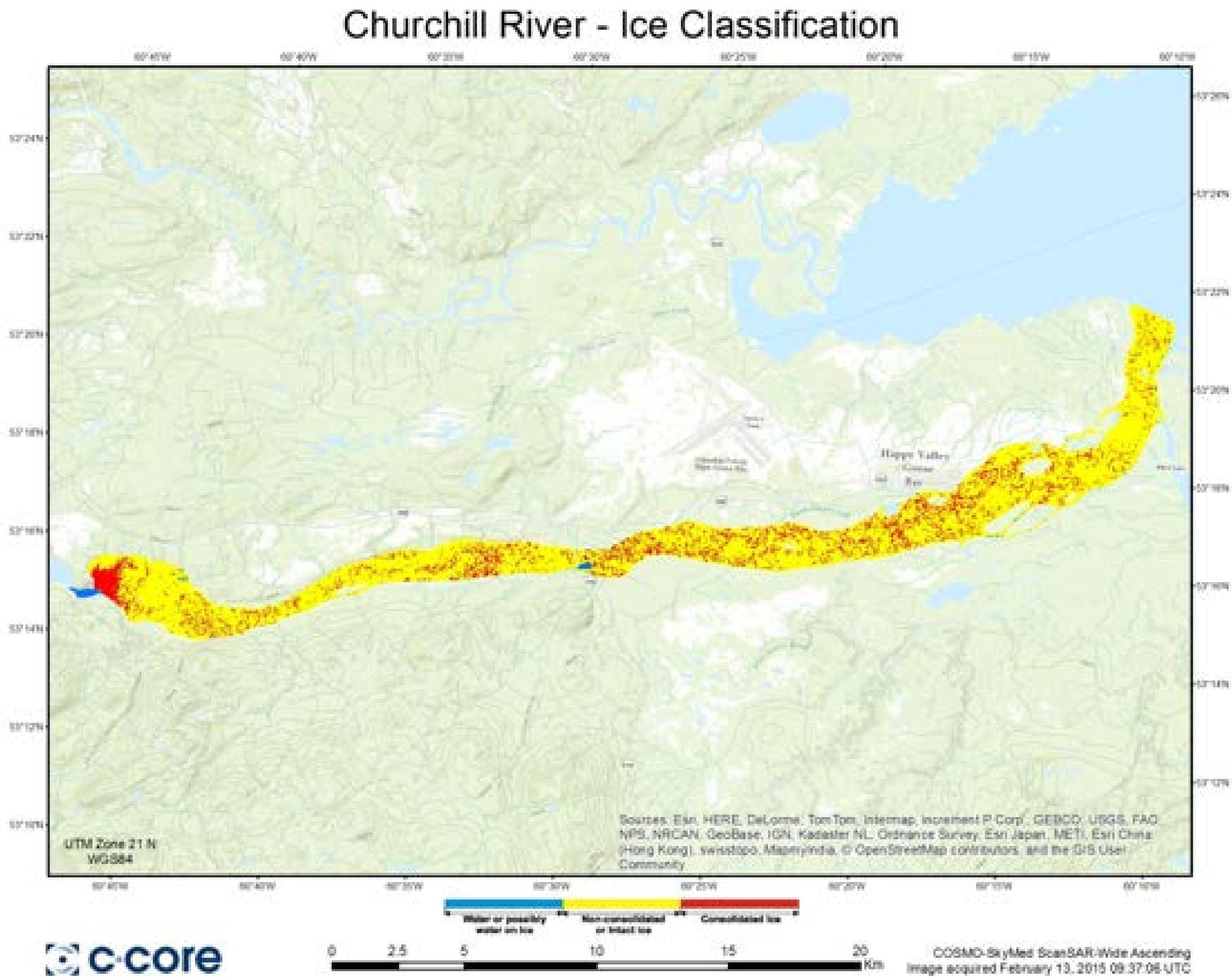
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 13, 2015 09:37:06 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
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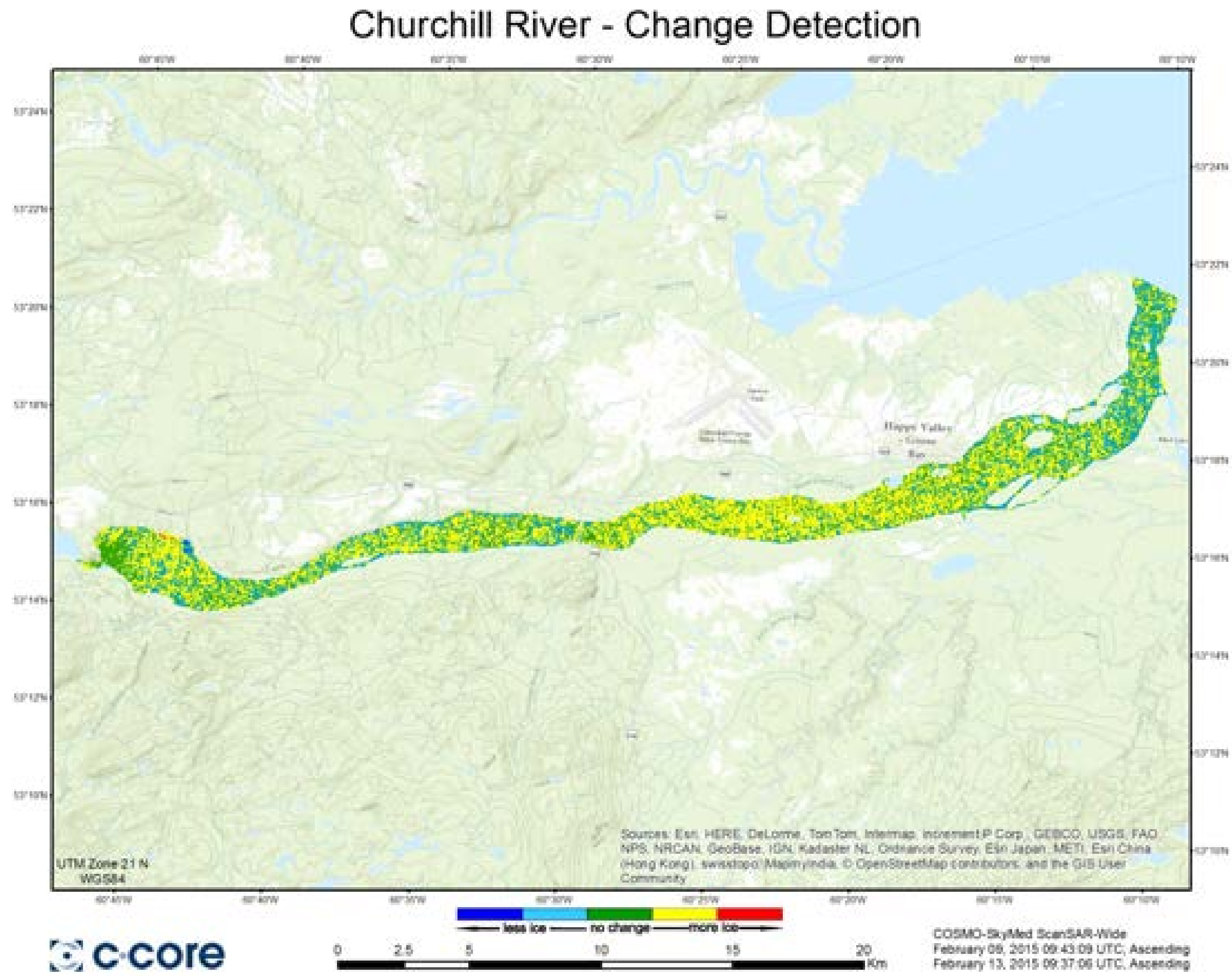
Km
c-core
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 13, 2015 09:37:06 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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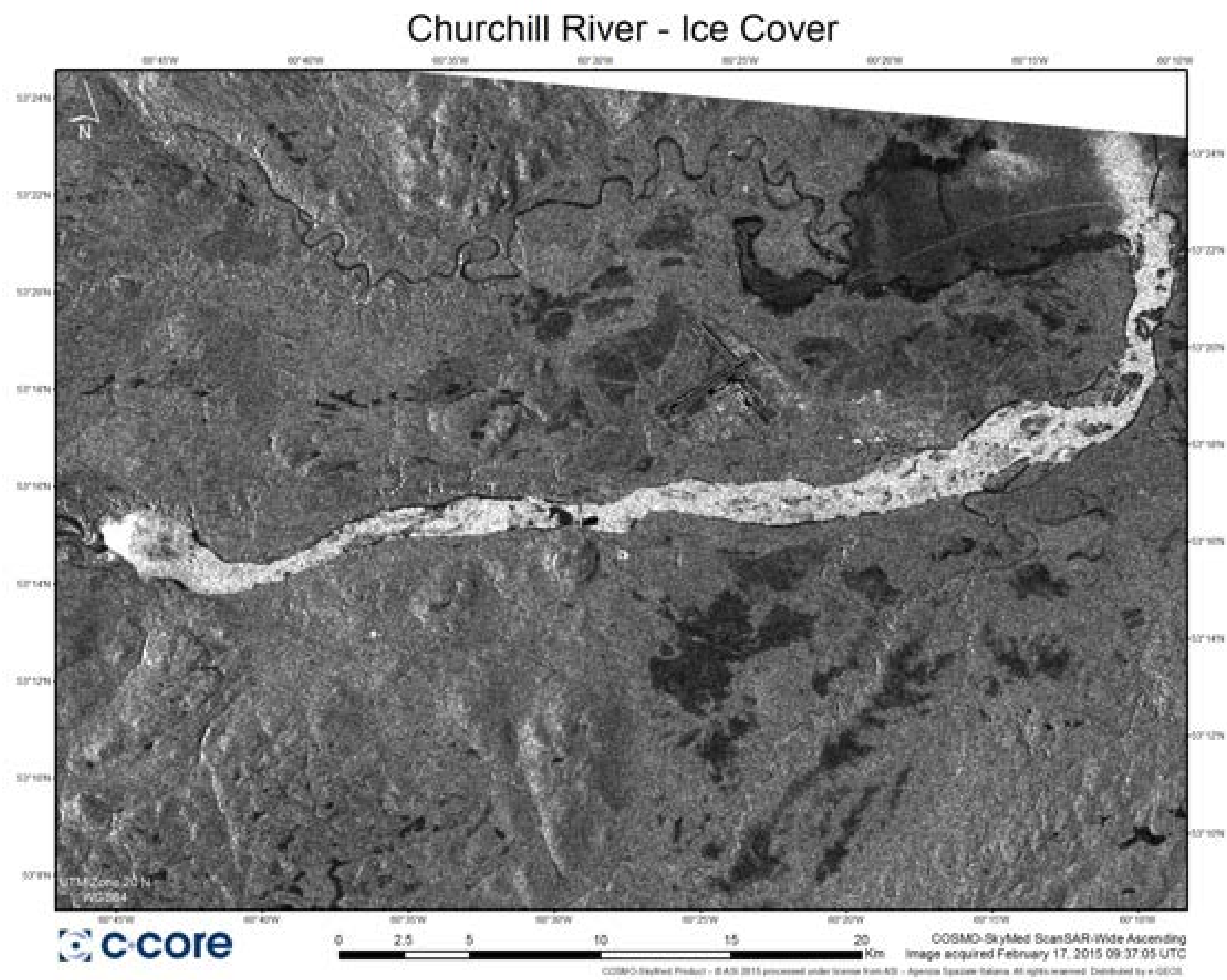
Km
c·core
COSMO-SkyMed ScanSAR-Wide
February 09, 2015 09:43:09 UTC, Ascending
February 13, 2015 09:37:06 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
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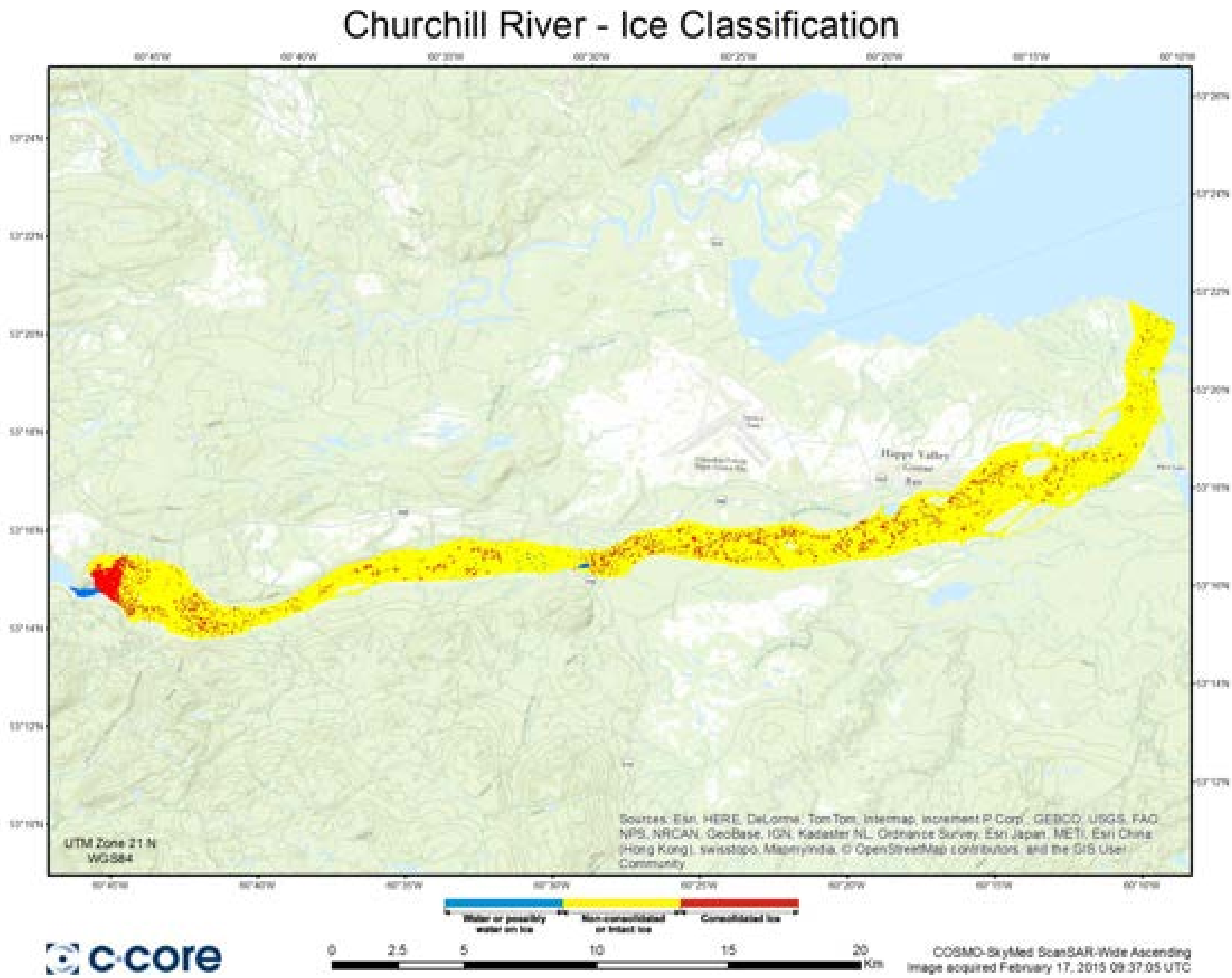
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 17, 2015 09:37:05 UTC


Churchill River - Ice Classification
Happy Valley
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
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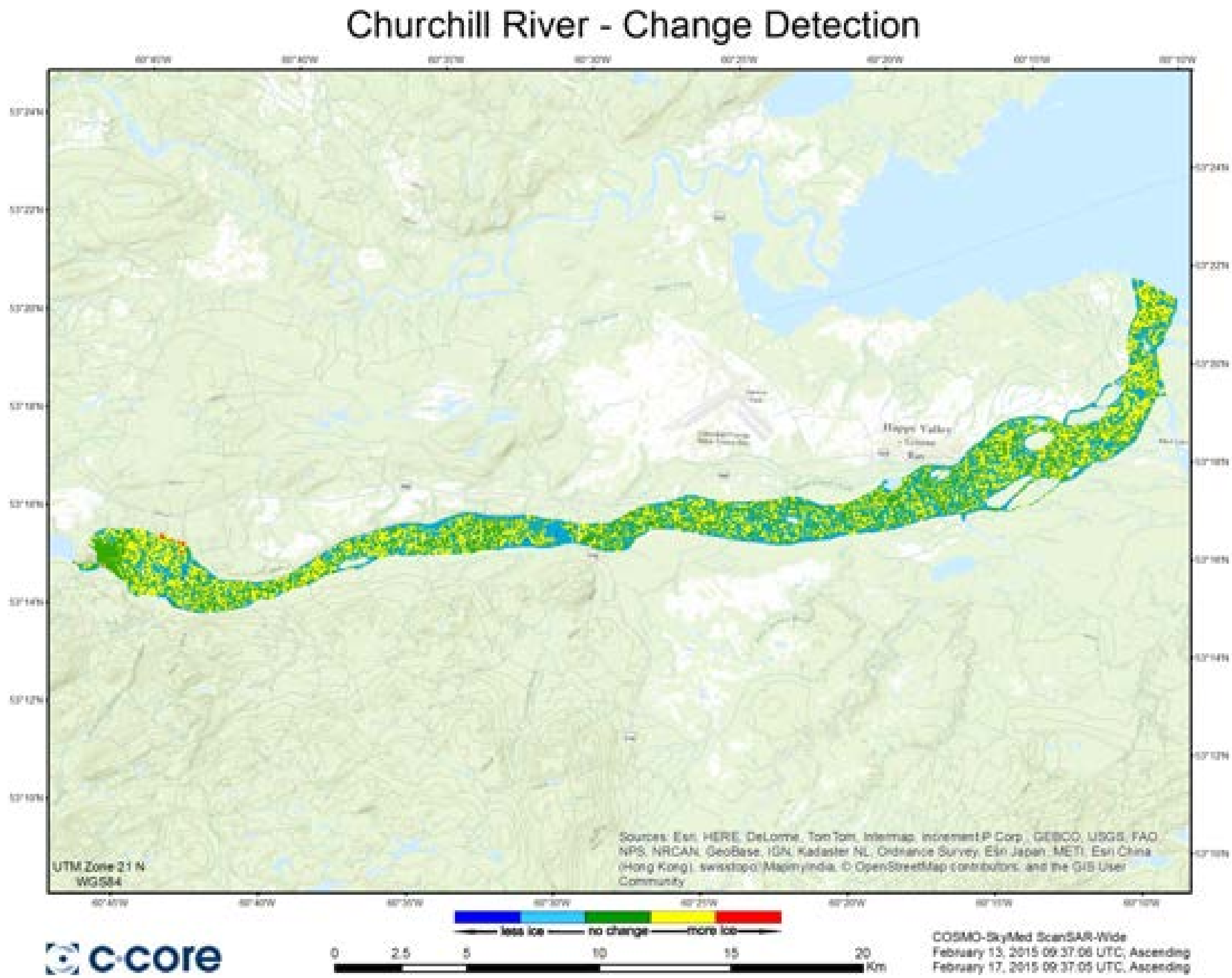
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 17, 2015 09:37:05 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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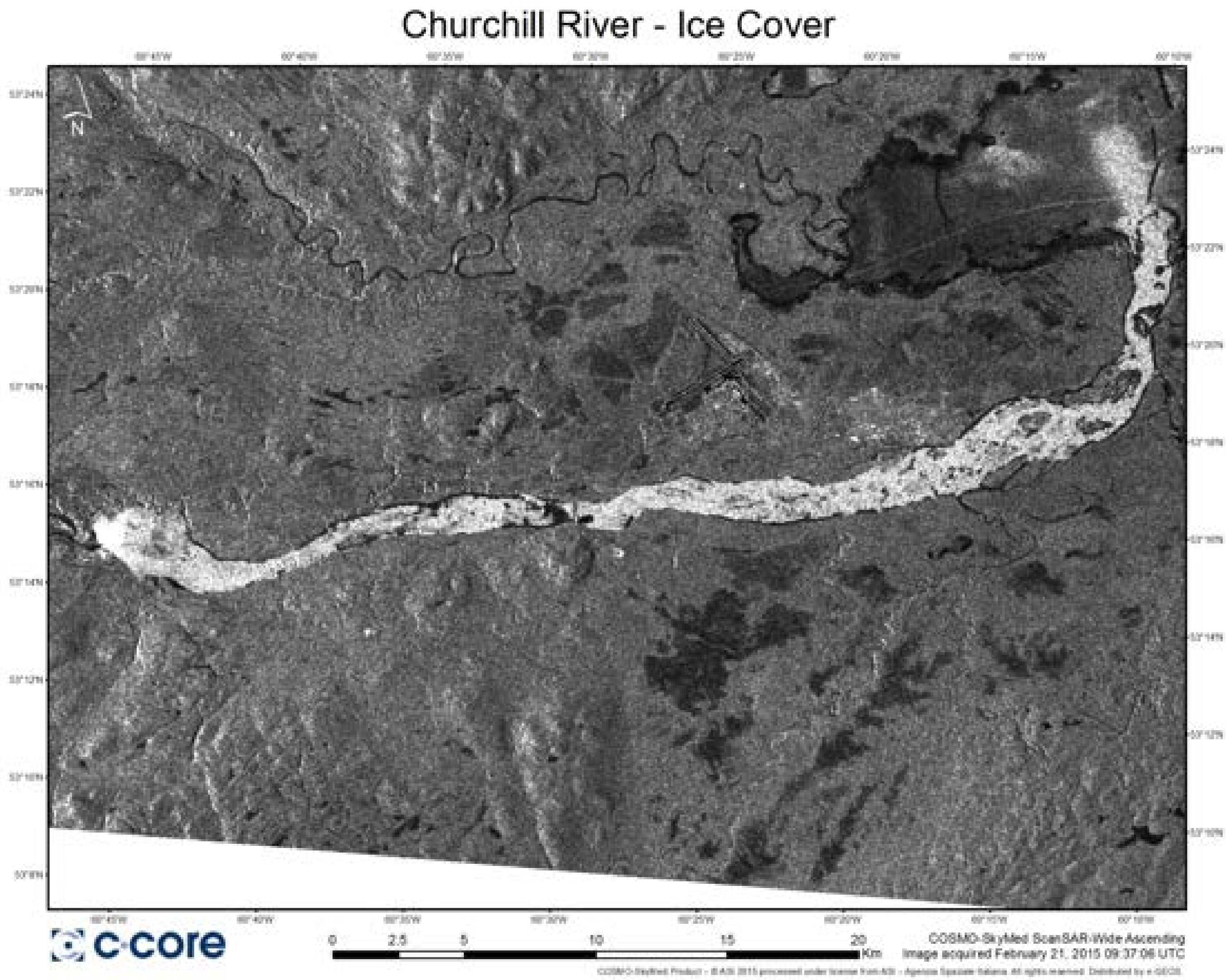
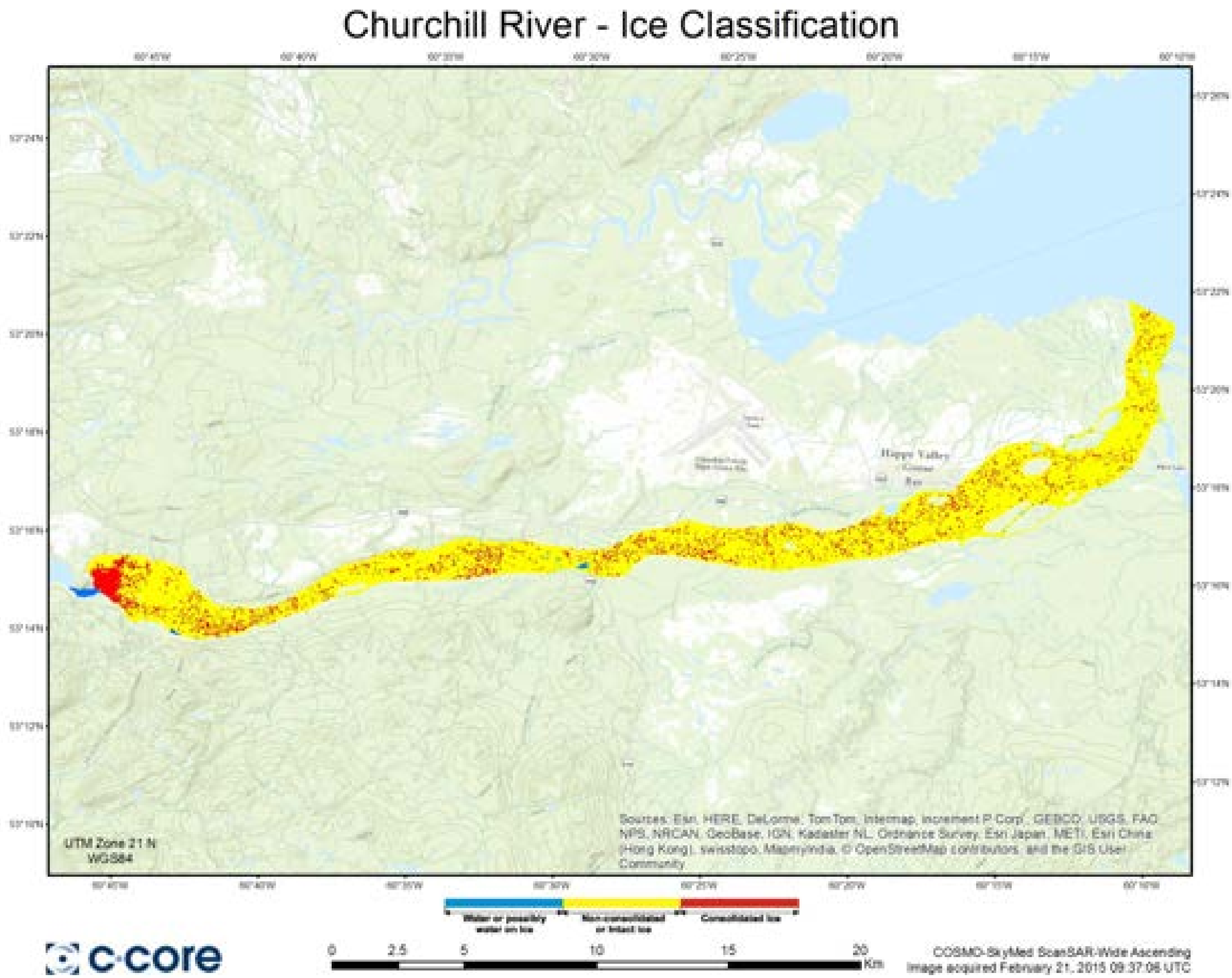
Km
c-core
COSMO-SkyMed ScanSAR-Wide
February 13, 2015 09:37:06 UTC, Ascending
February 17, 2015 09:37:05 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 21, 2015 09:37:06 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Happy Valley - Goose Bay
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
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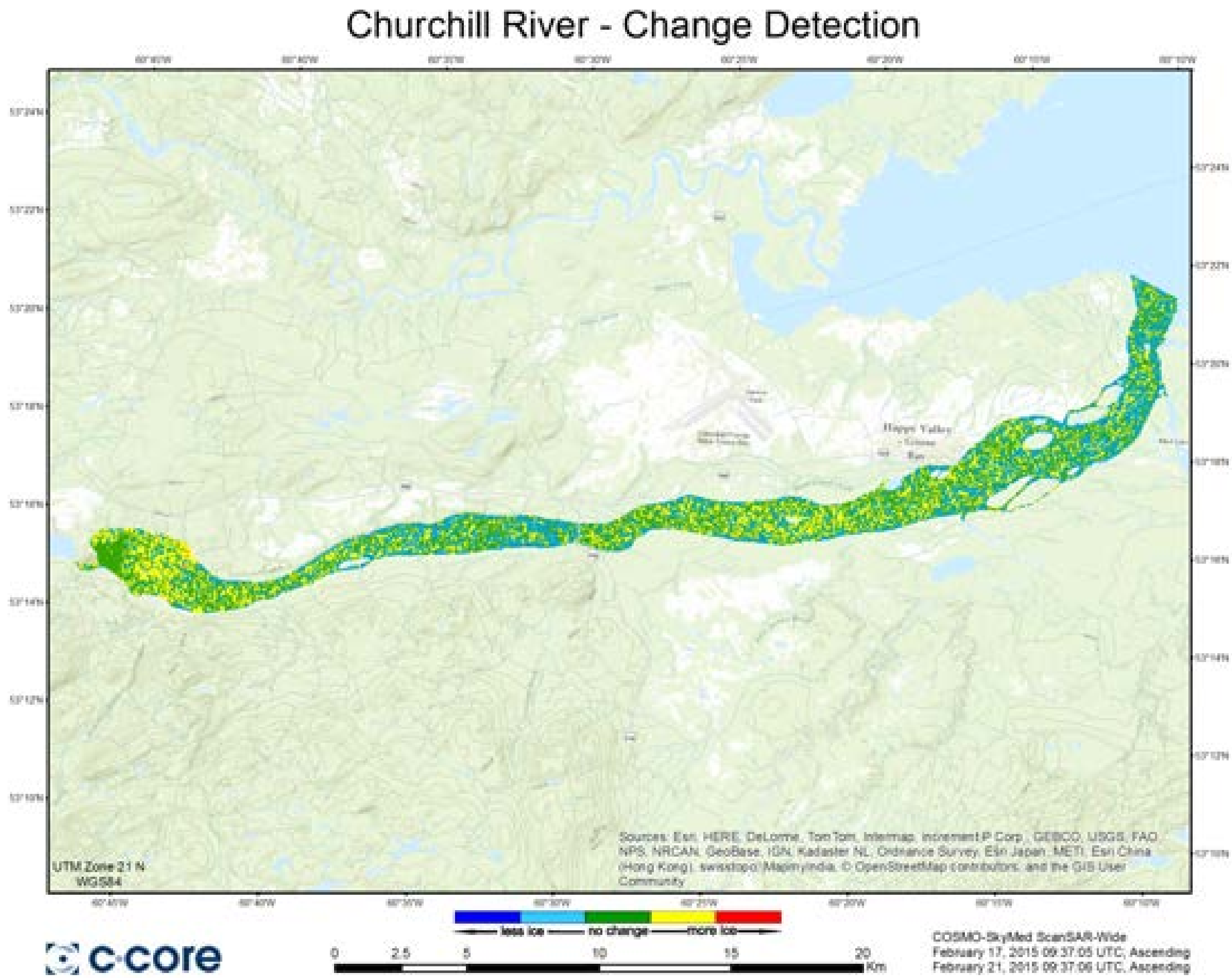
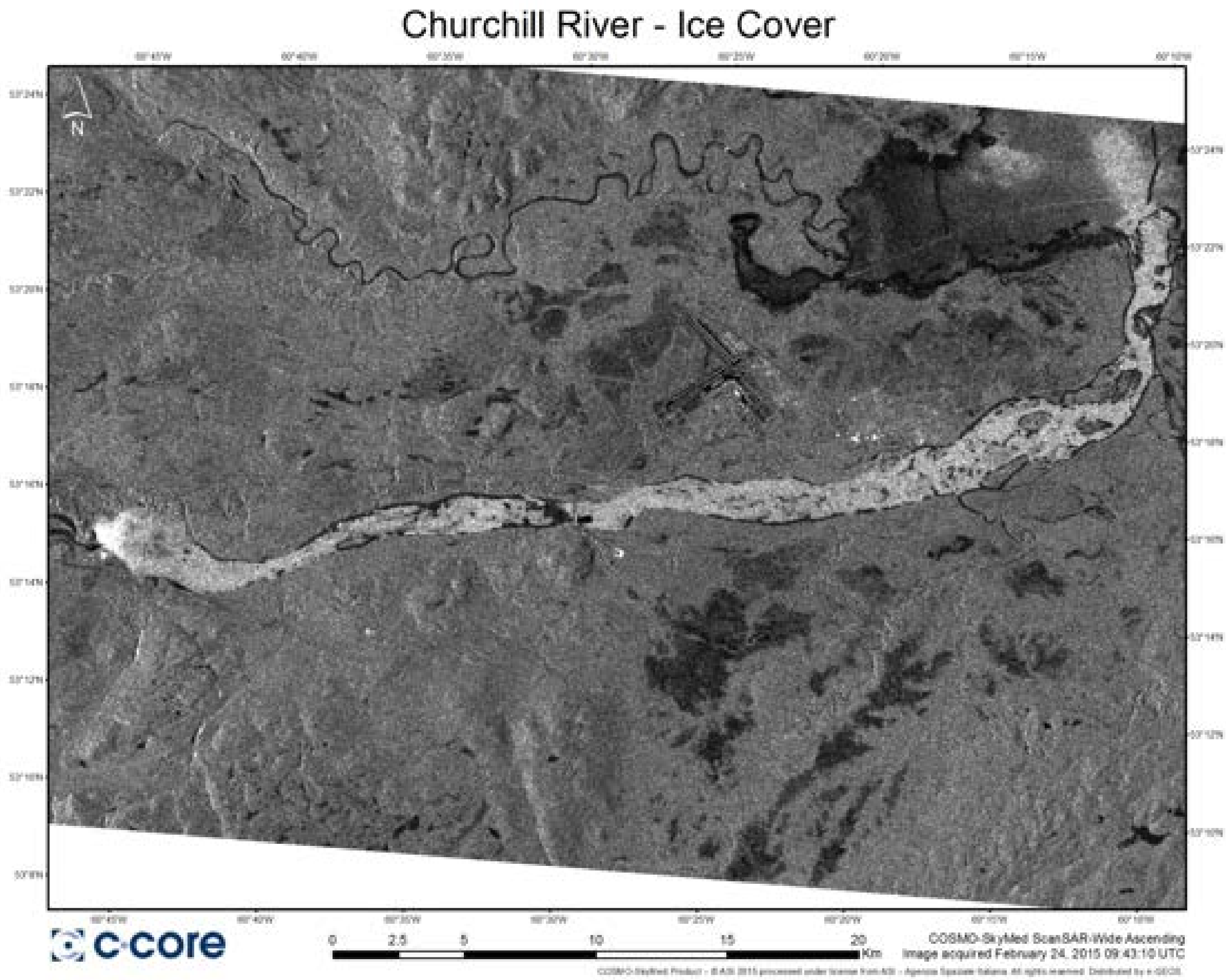
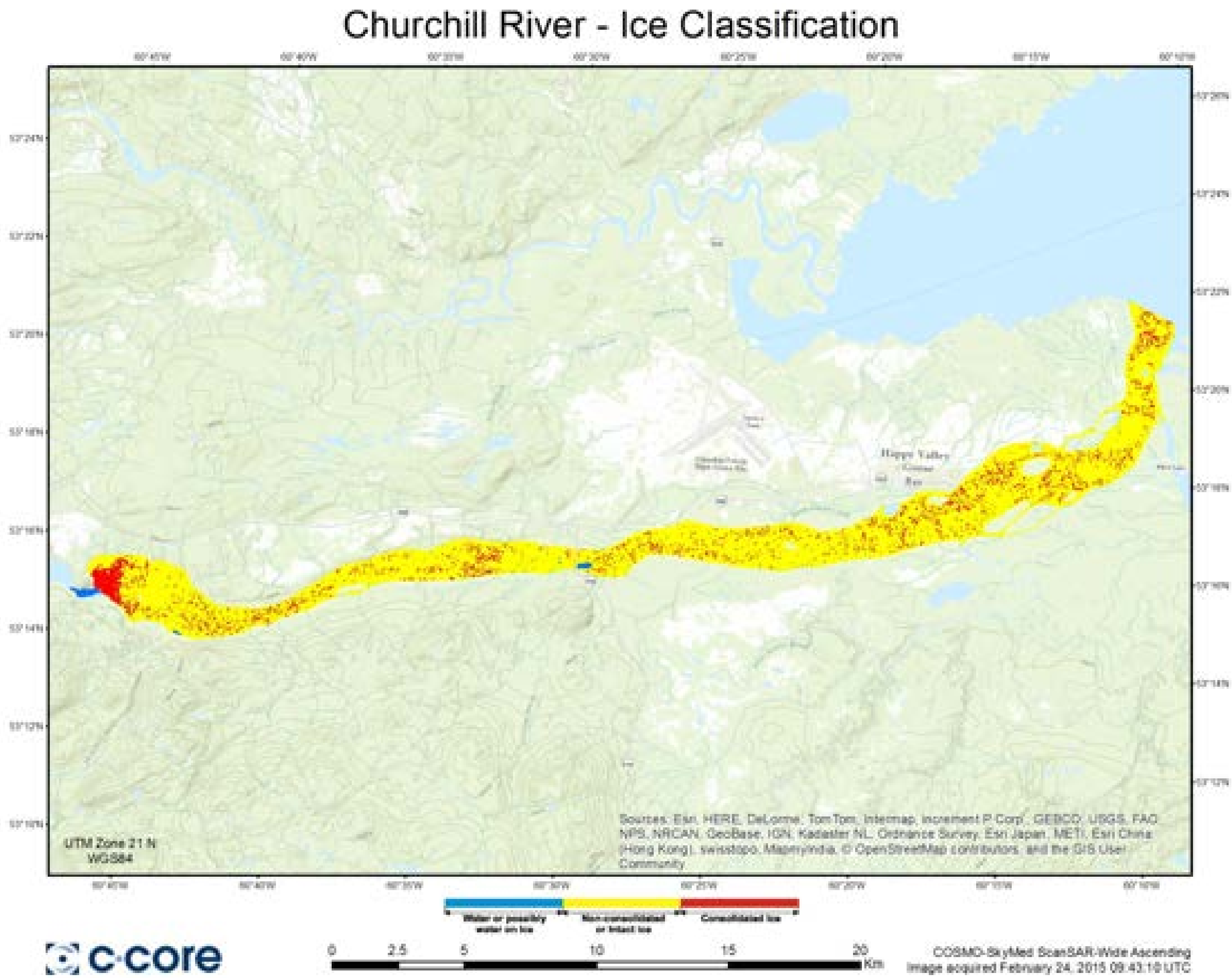
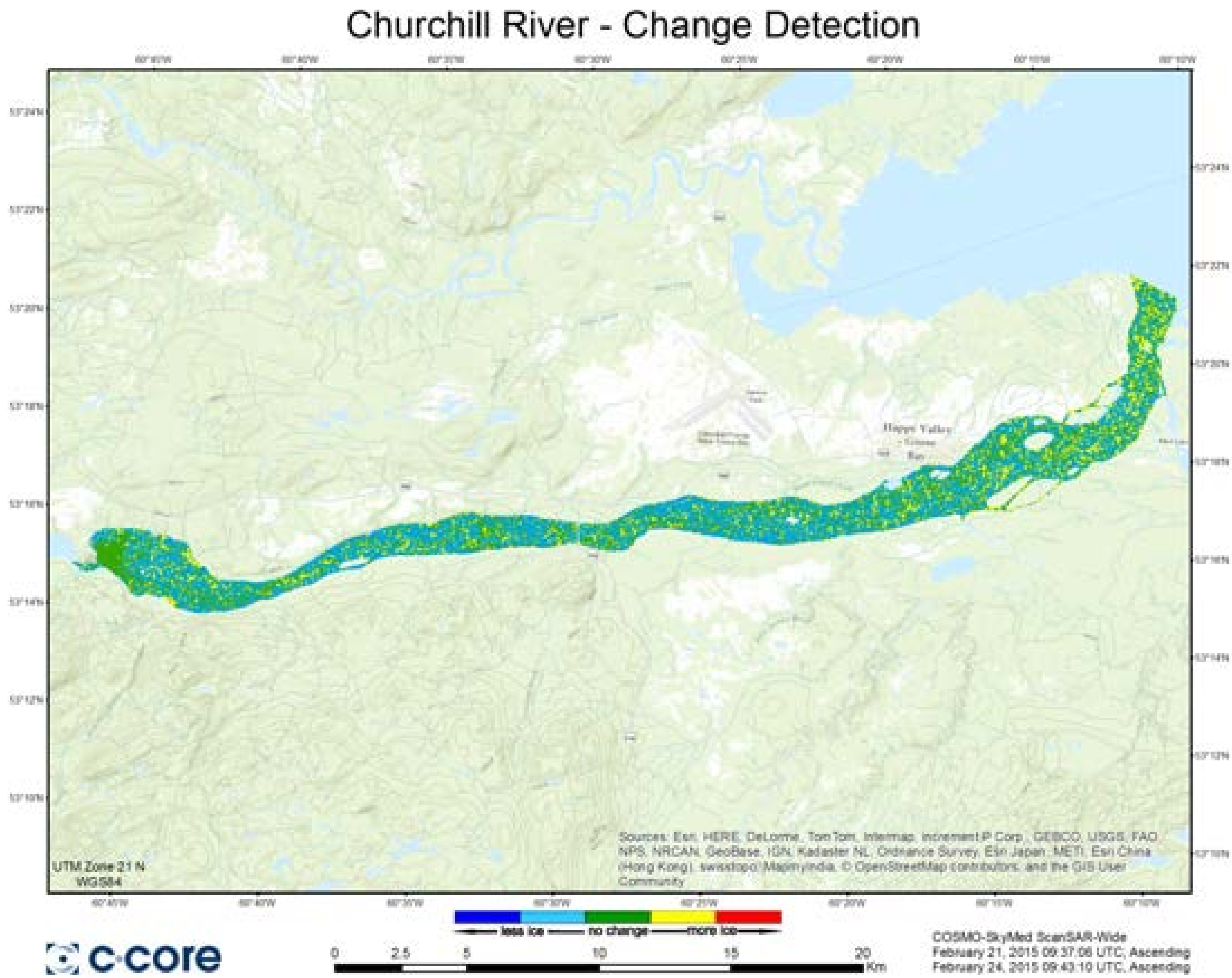
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 21, 2015 09:37:06 UTC

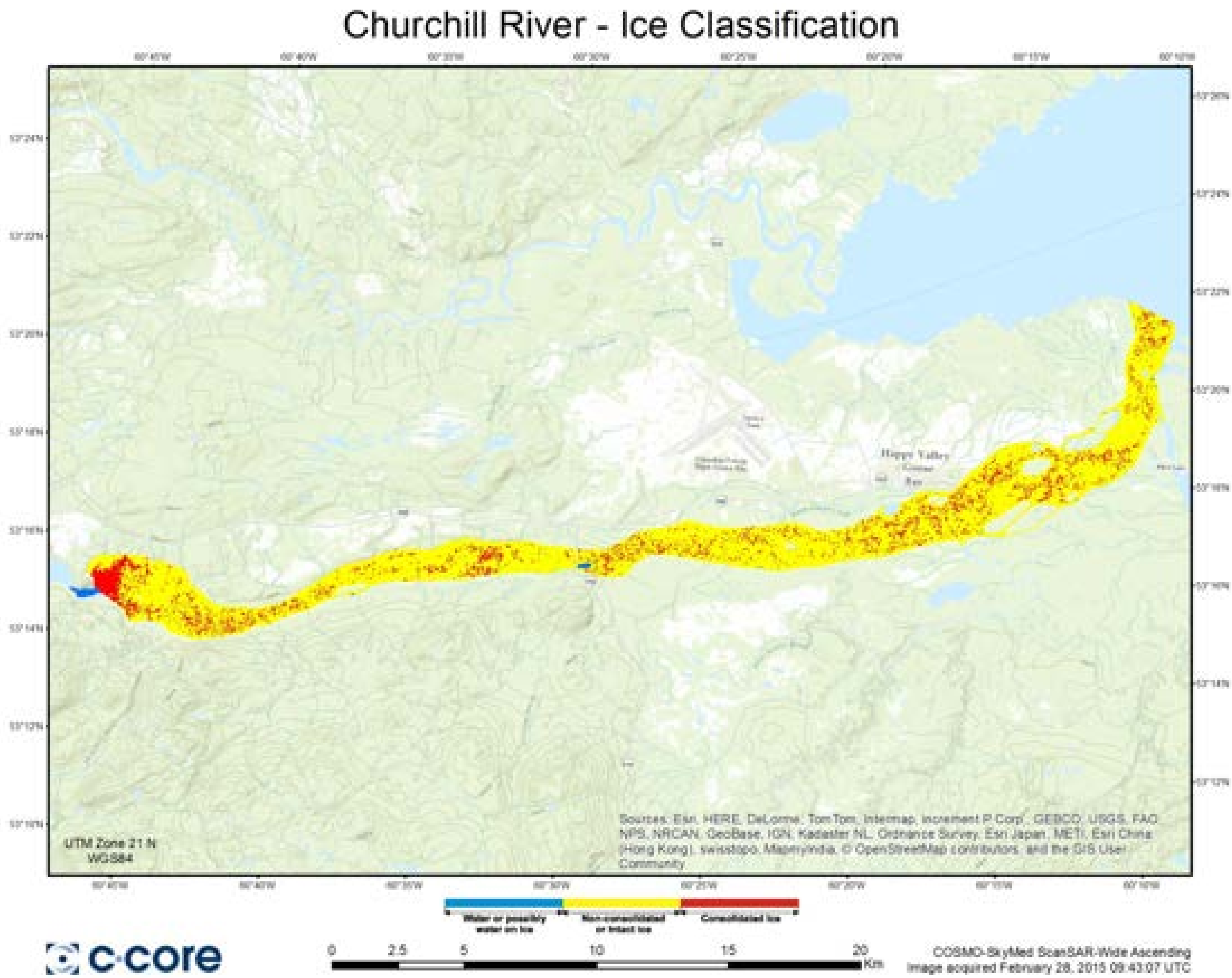

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
c-core
COSMO-SkyMed ScanSAR-Wide
February 17, 2015 09:37:05 UTC, Ascending
February 21, 2015 09:37:06 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 24, 2015 09:43:10 UTC


Churchill River - Ice Classification
Happy Valley
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 24, 2015 09:43:10 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
February 21, 2015 09:37:06 UTC, Ascending
February 24, 2015 09:43:10 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 28, 2015 09:43:07 UTC


Churchill River - Ice Classification
Happy Valley Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
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2.5
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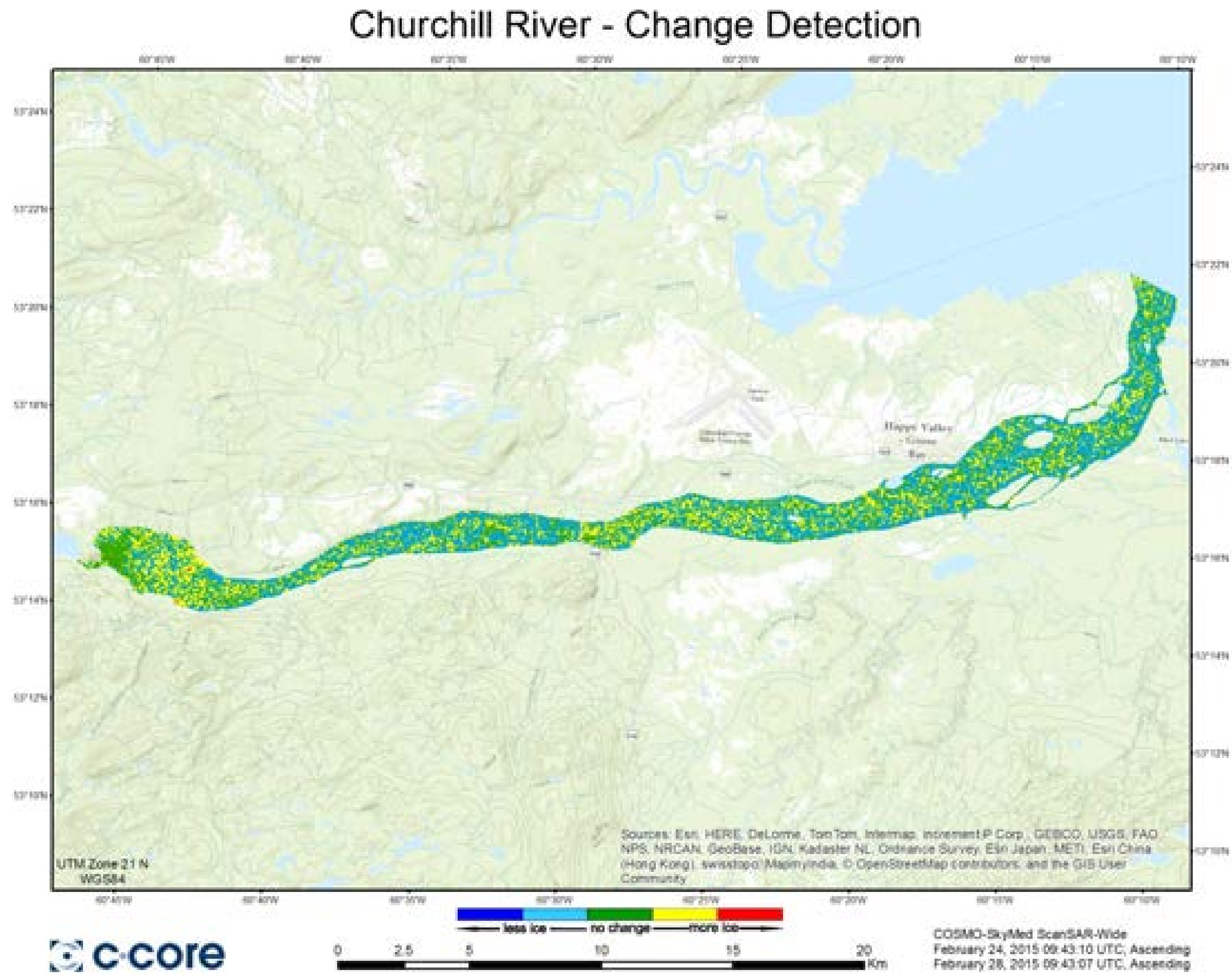
Km
c-core
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired February 28, 2015 09:43:07 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
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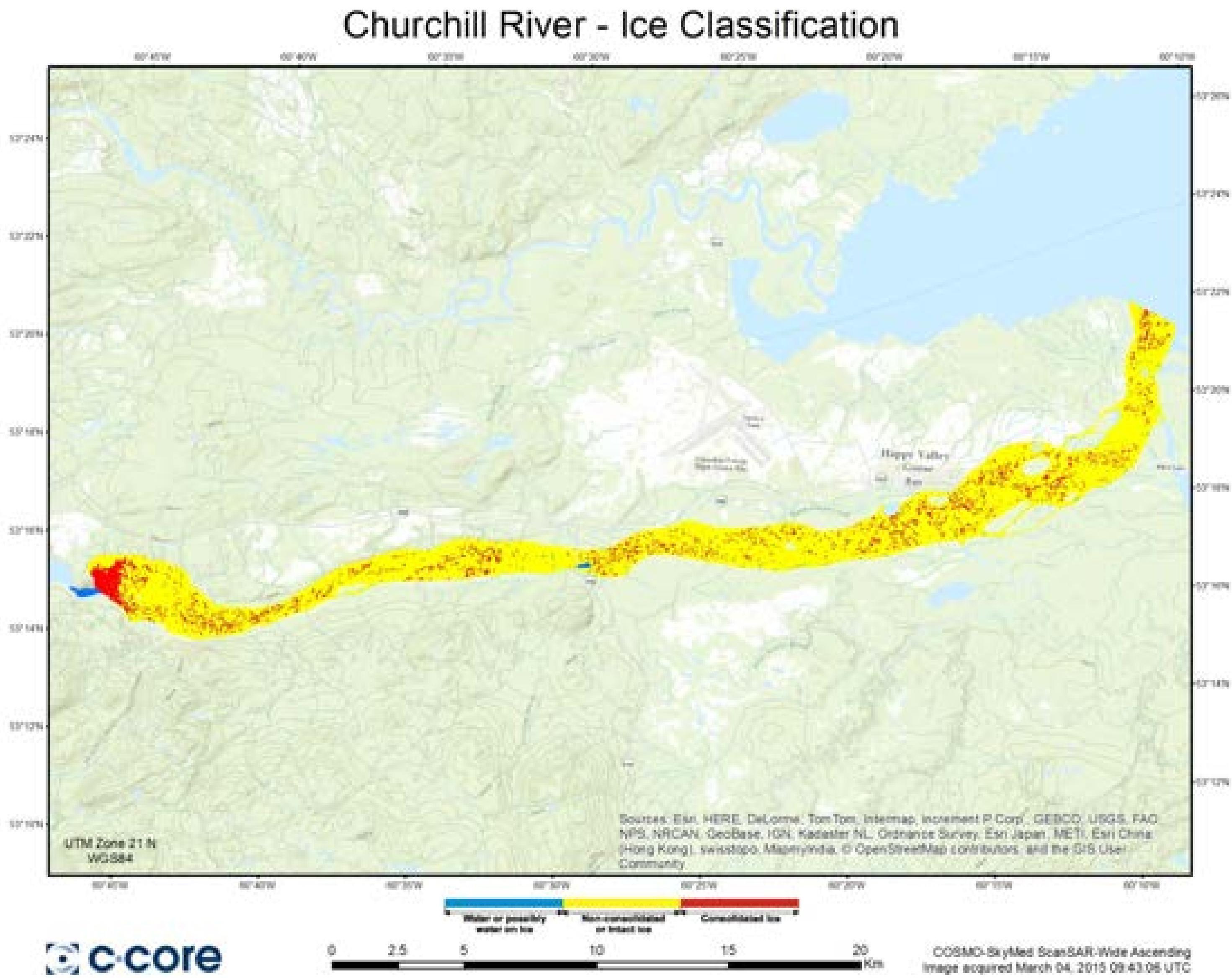
20
Km
c-core
COSMO-SkyMed ScanSAR-Wide
February 24, 2015 09:43:10 UTC, Ascending
February 28, 2015 09:43:07 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 04, 2015 09:43:06 UTC


Churchill River - Ice Classification
Happy Valley
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
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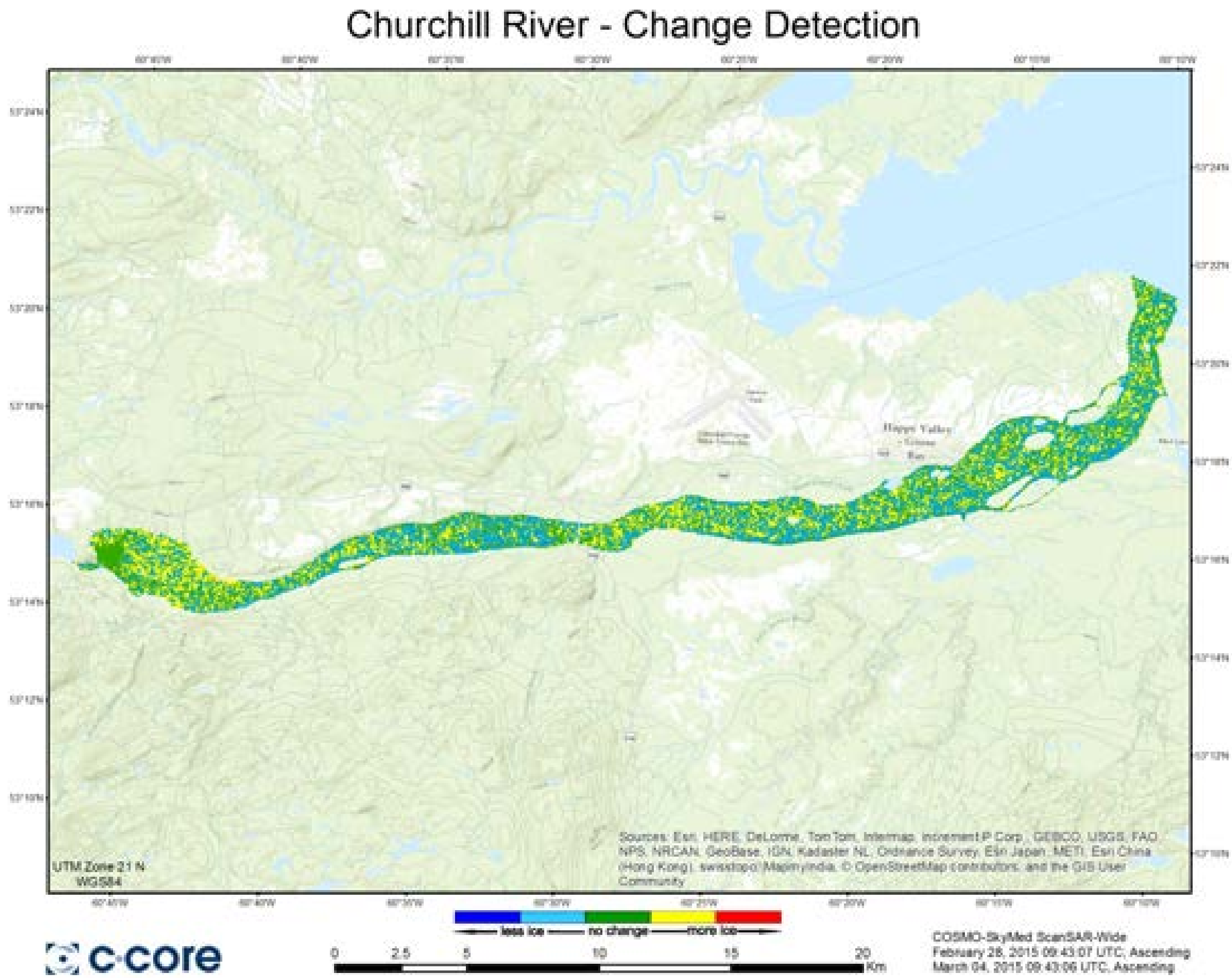
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 04, 2015 09:43:06 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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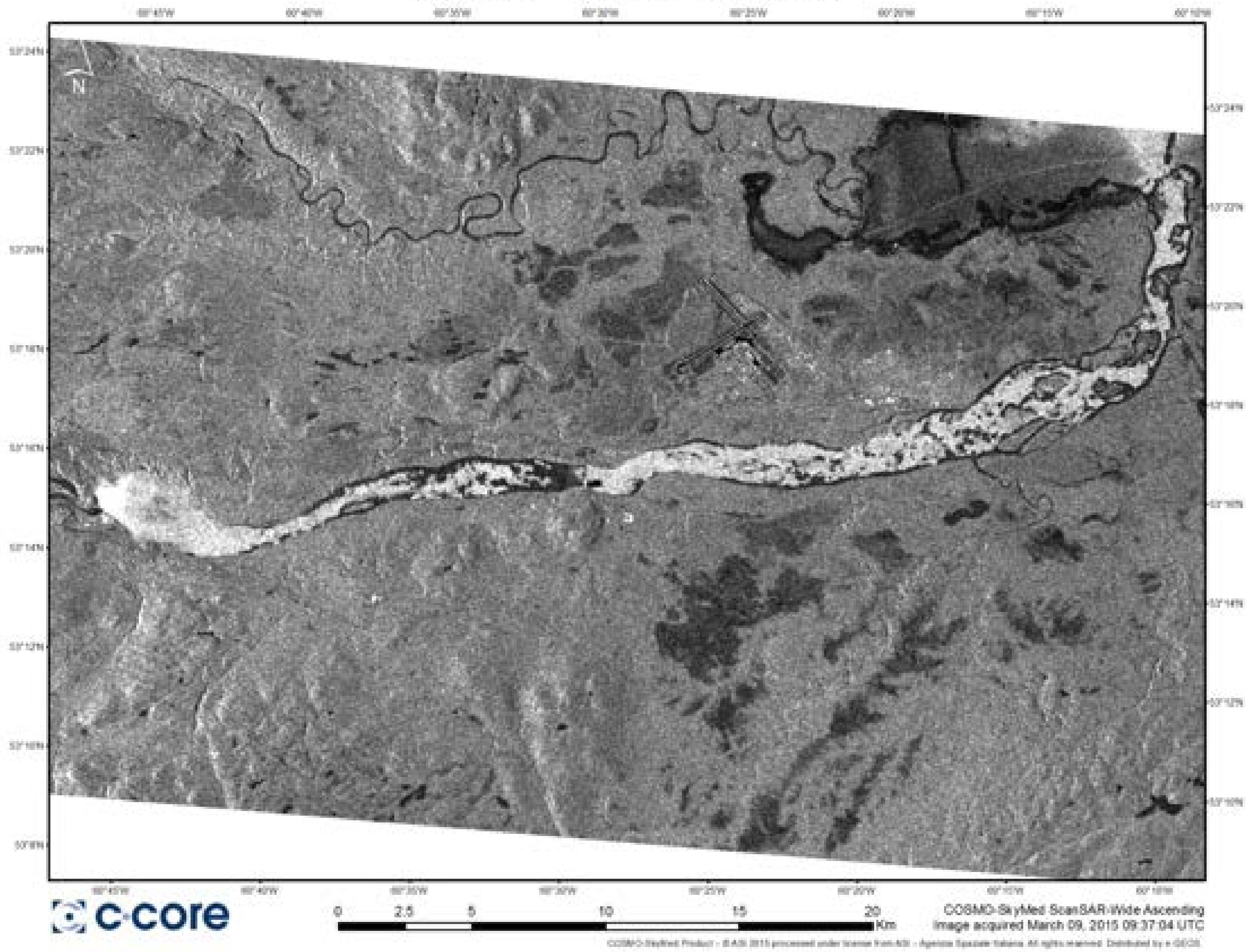
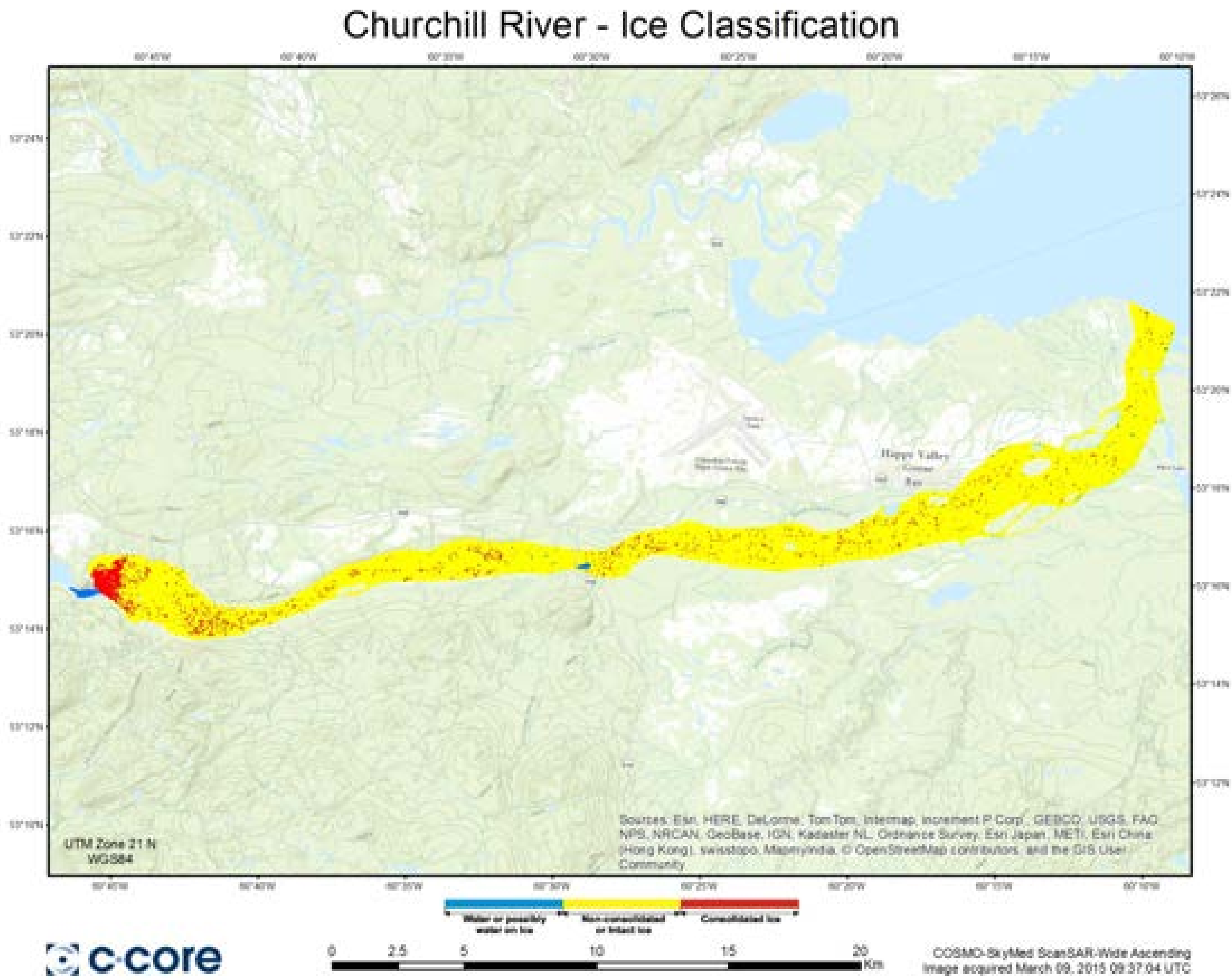
Km
COSMO-SkyMed ScanSAR-Wide
February 28, 2015 09:43:07 UTC, Ascending
March 04, 2015 09:43:06 UTC, Ascending

Churchill River - Ice Cover




Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
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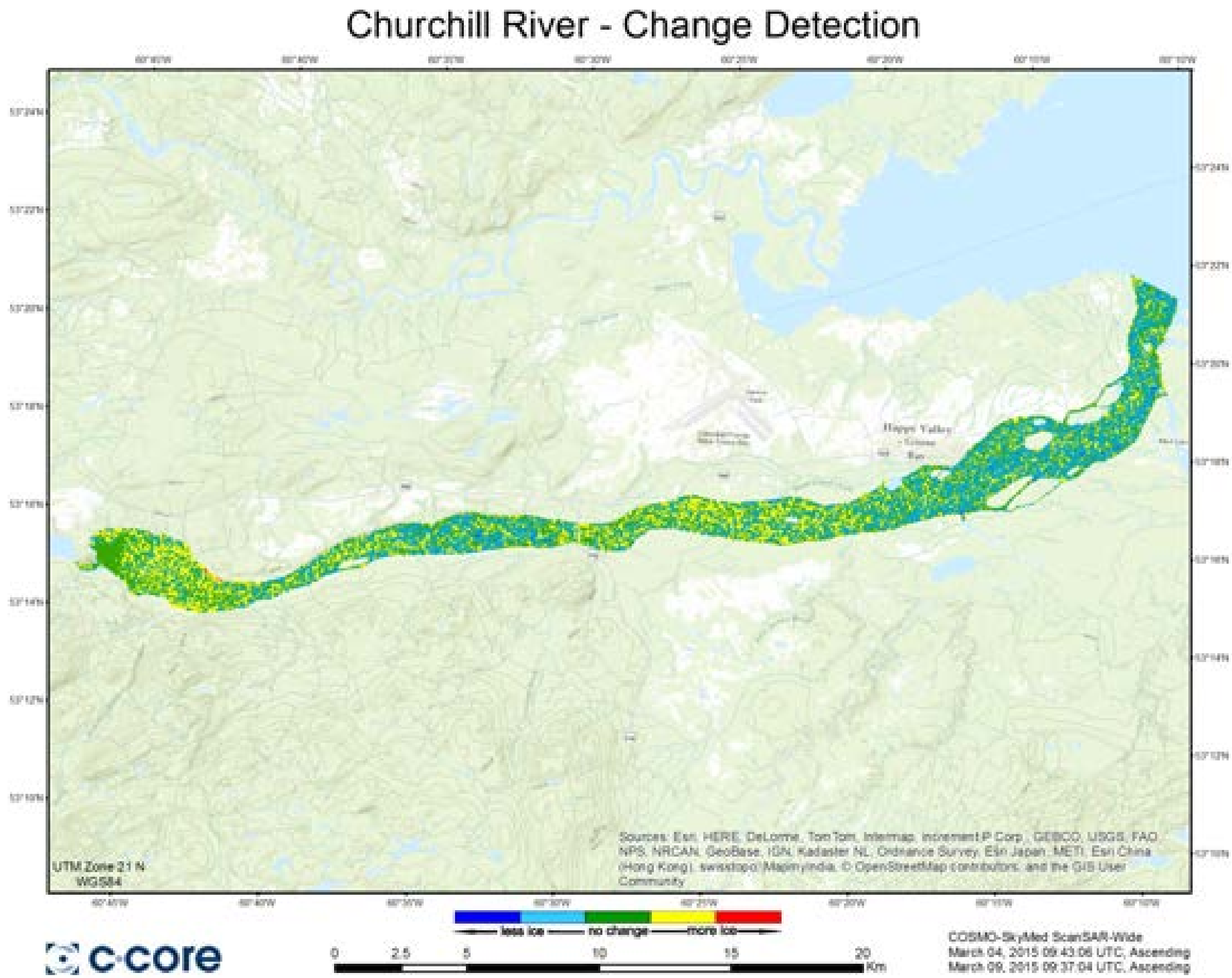
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 09, 2015 09:37:04 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
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10
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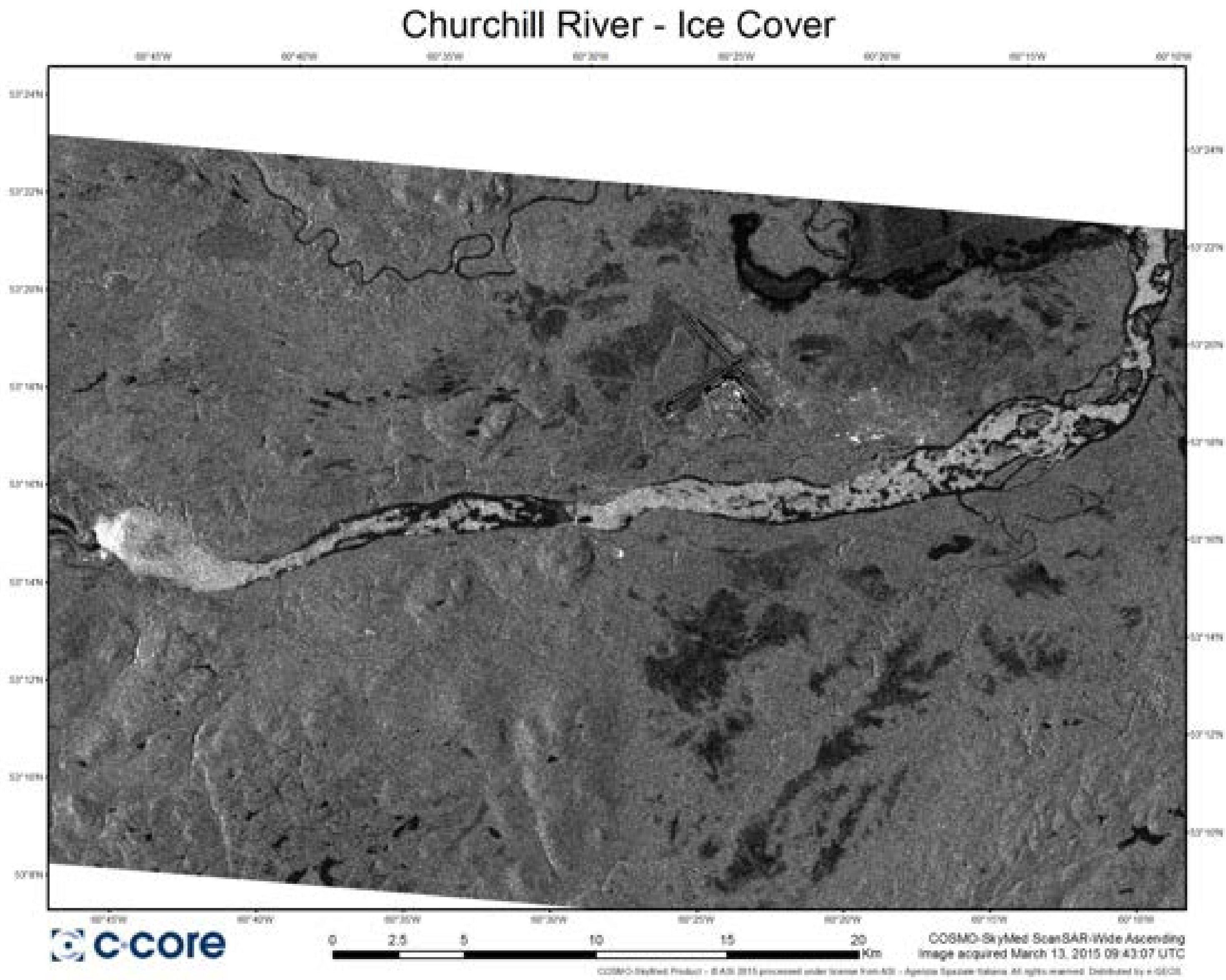
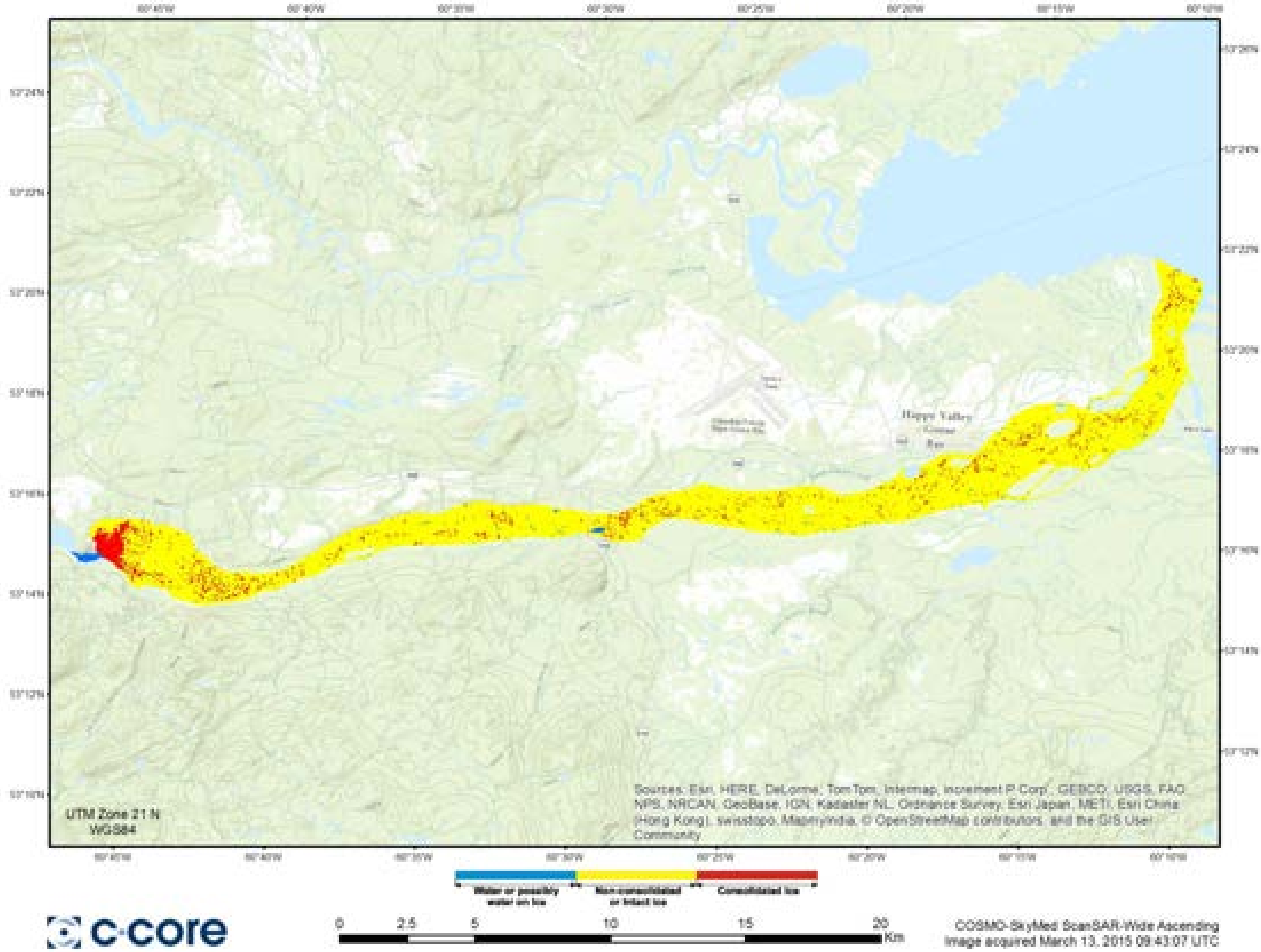
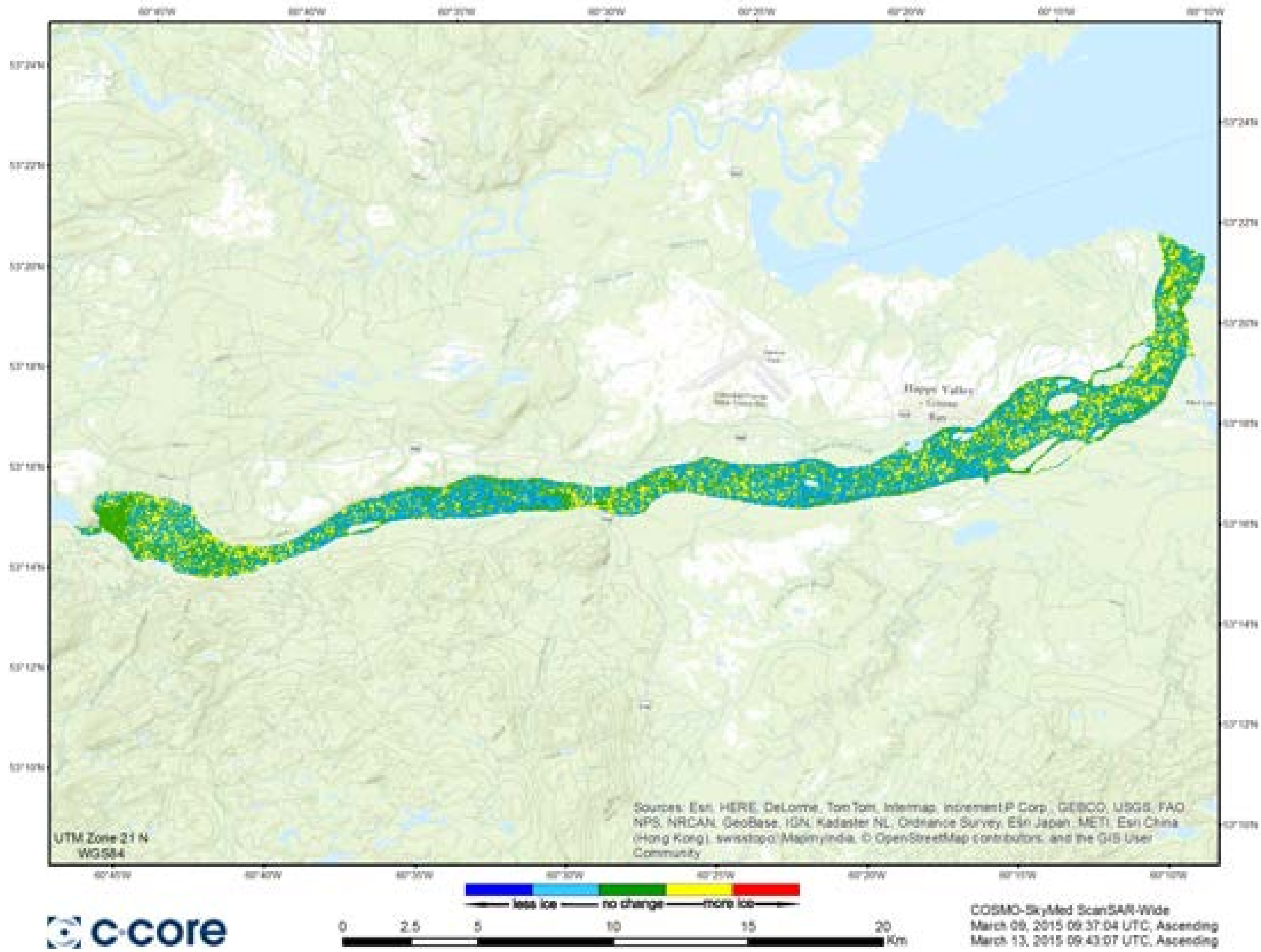
Km
c-core
COSMO-SkyMed ScanSAR-Wide
March 04, 2015 09:43:06 UTC, Ascending
March 09, 2015 09:37:04 UTC, Ascending


Churchill River - Ice Cover
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 13, 2015 09:43:07 UTC

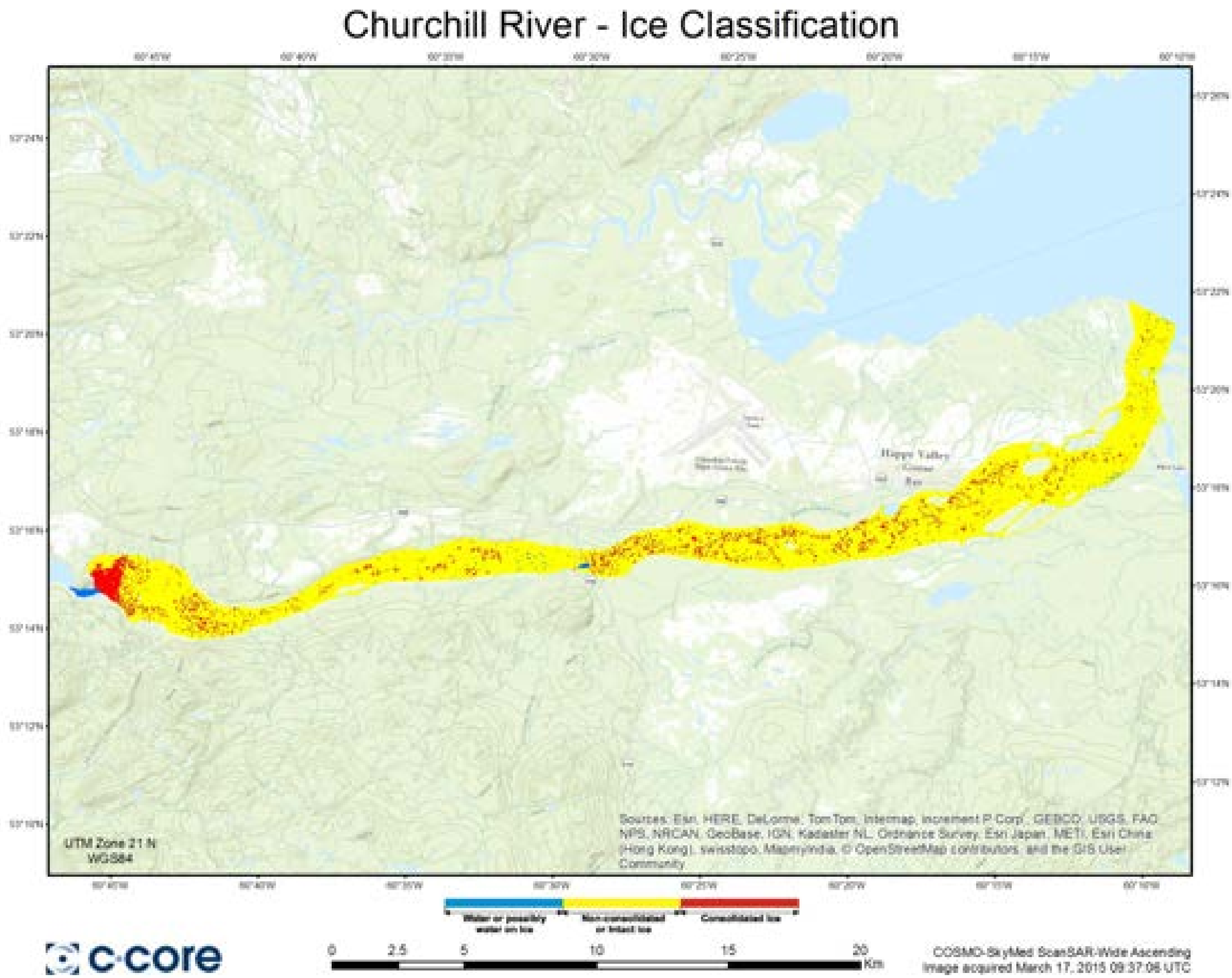
Churchill River - Ice Classification



Churchill River - Change Detection




Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 17, 2015 09:37:06 UTC


Churchill River - Ice Classification
Happy Valley Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
0
2.5
5
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15
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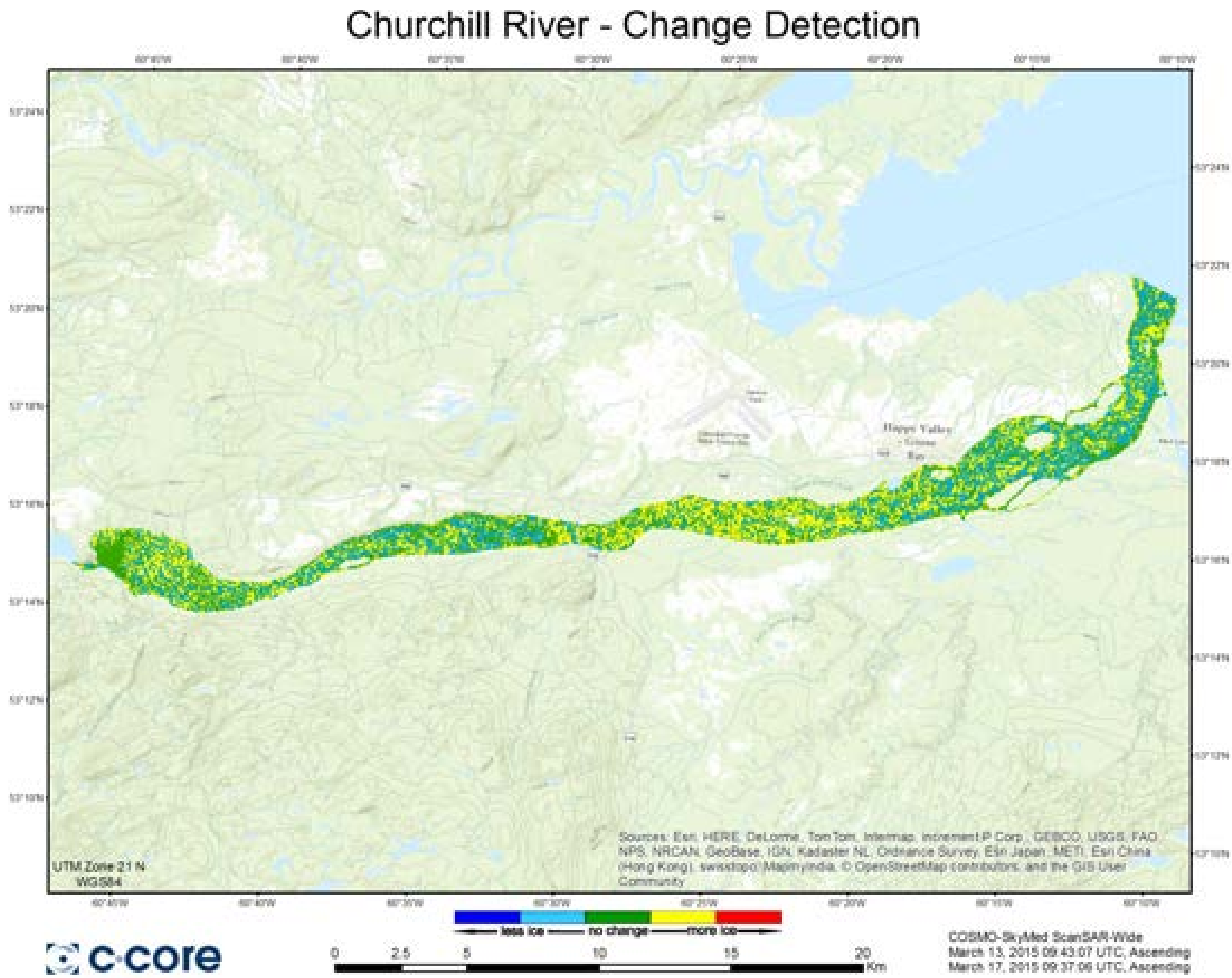
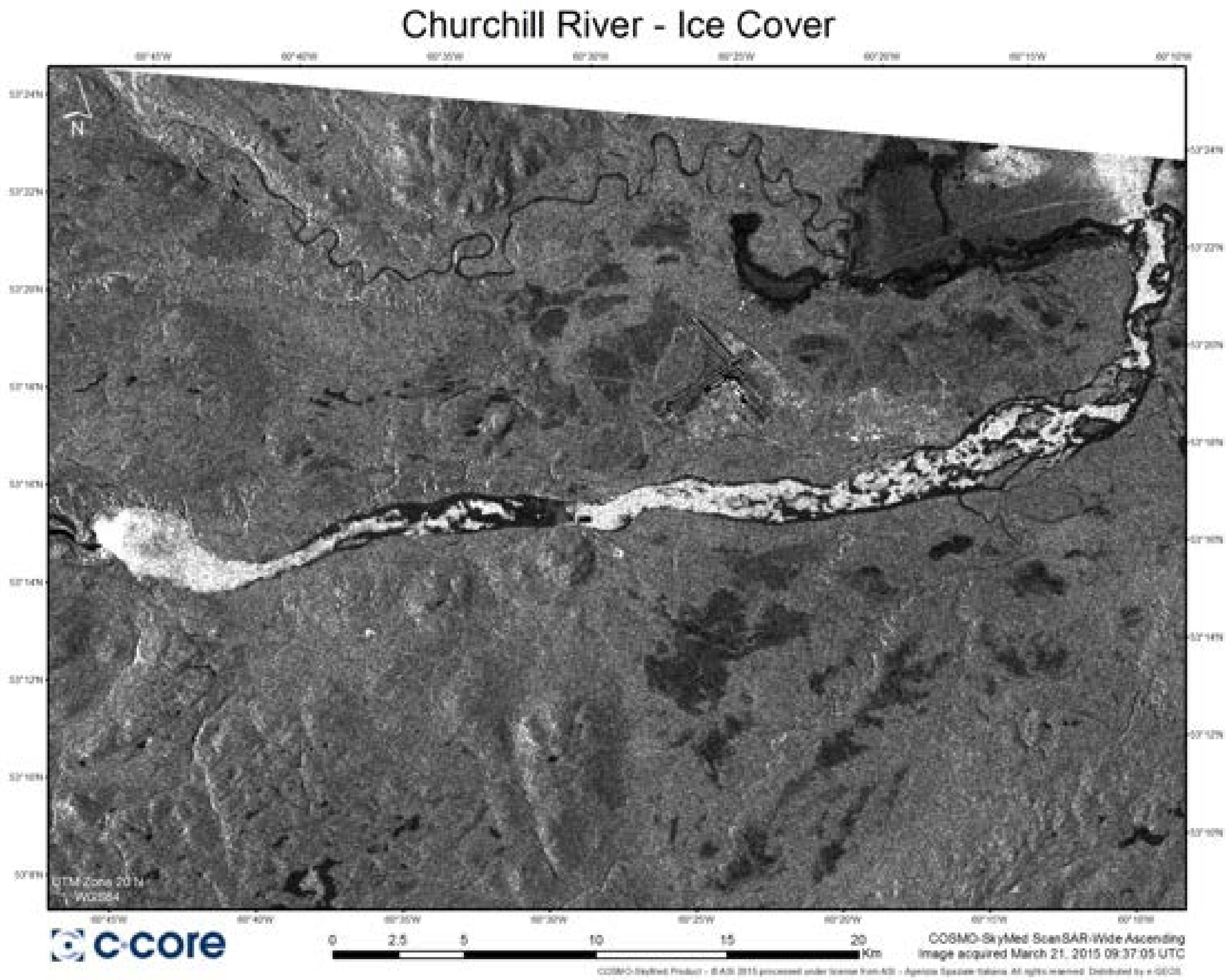
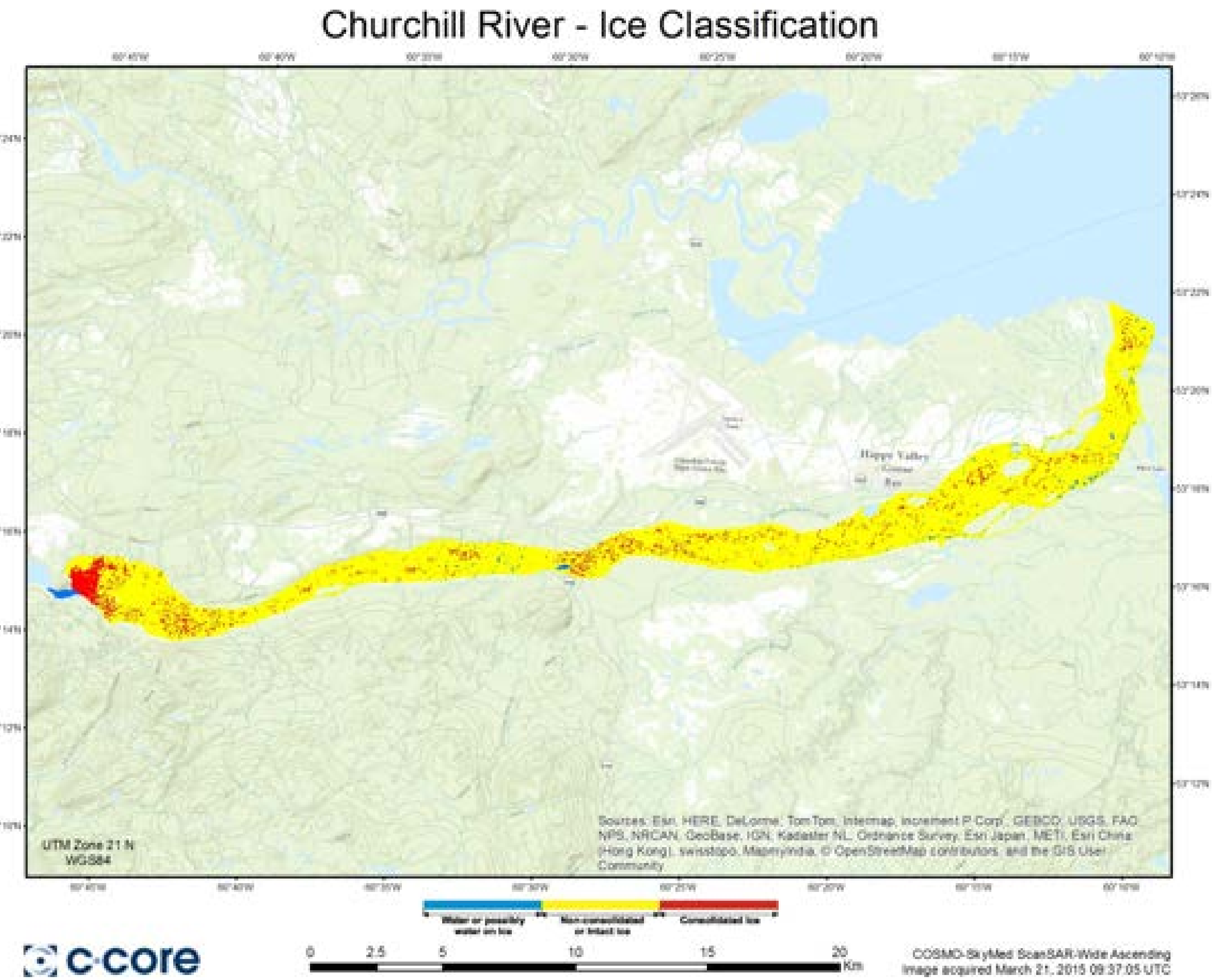
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 17, 2015 09:37:06 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
March 13, 2015 09:43:07 UTC, Ascending
March 17, 2015 09:37:06 UTC, Ascending


Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 21, 2015 09:37:05 UTC


Churchill River - Ice Classification
Happy Valley
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
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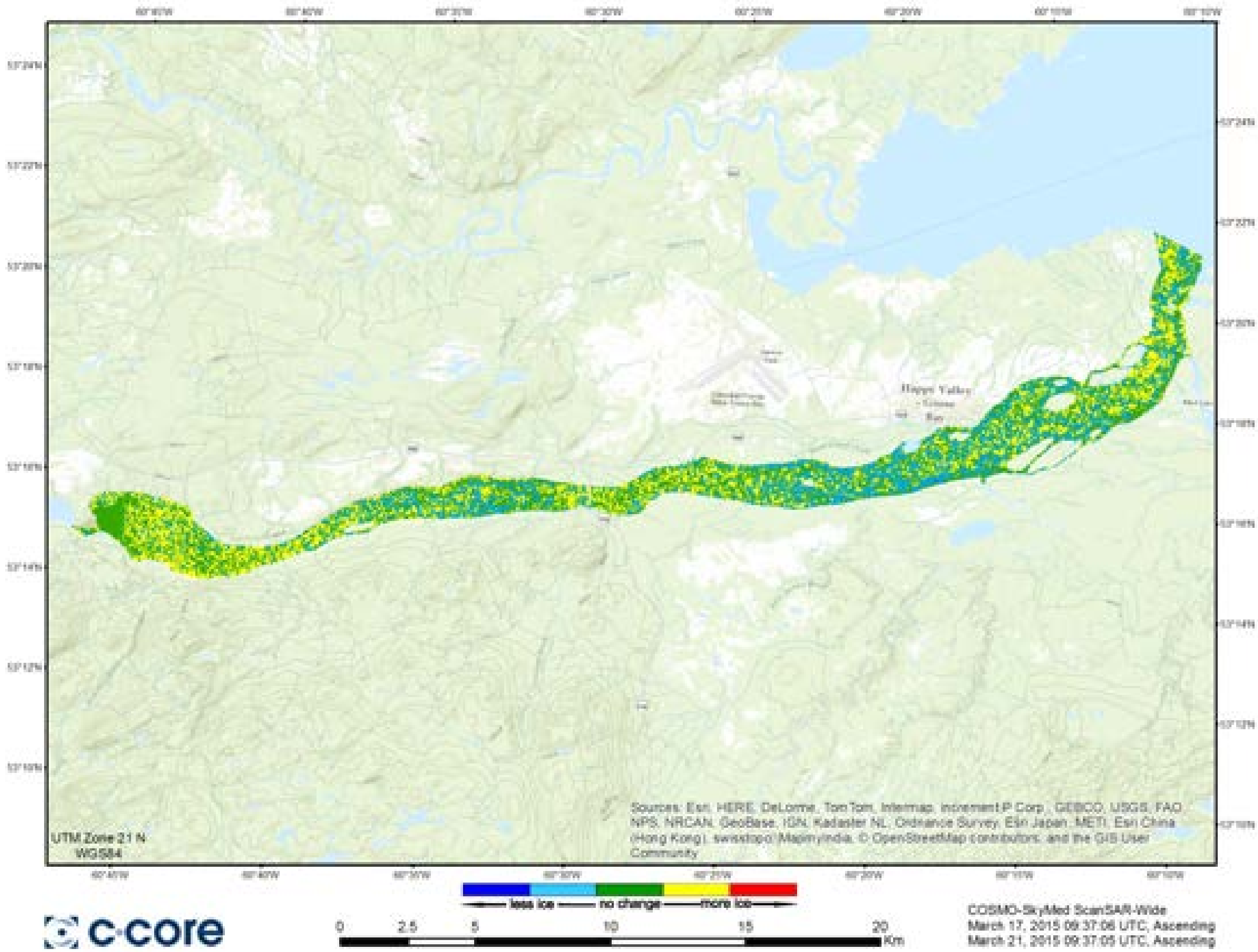
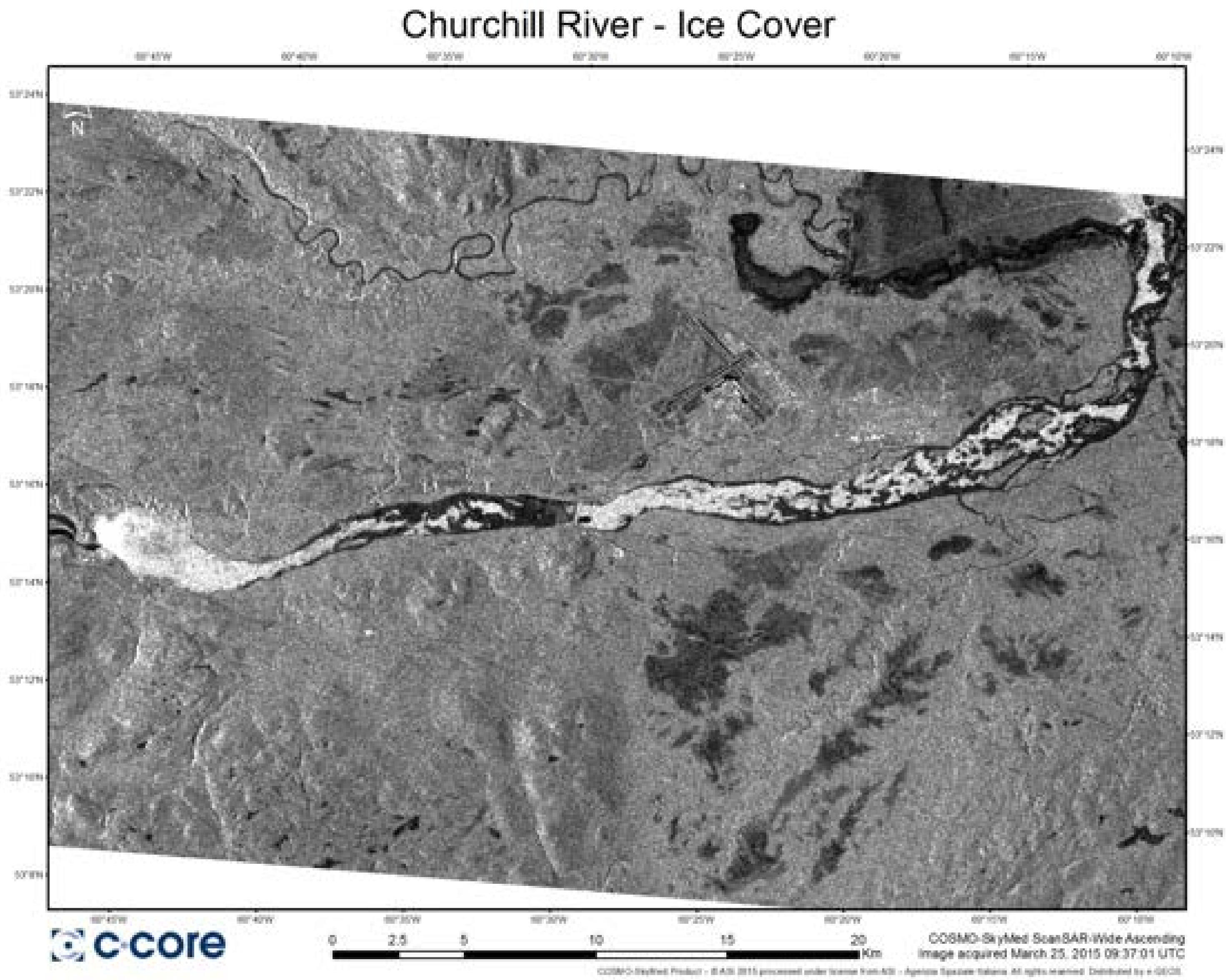
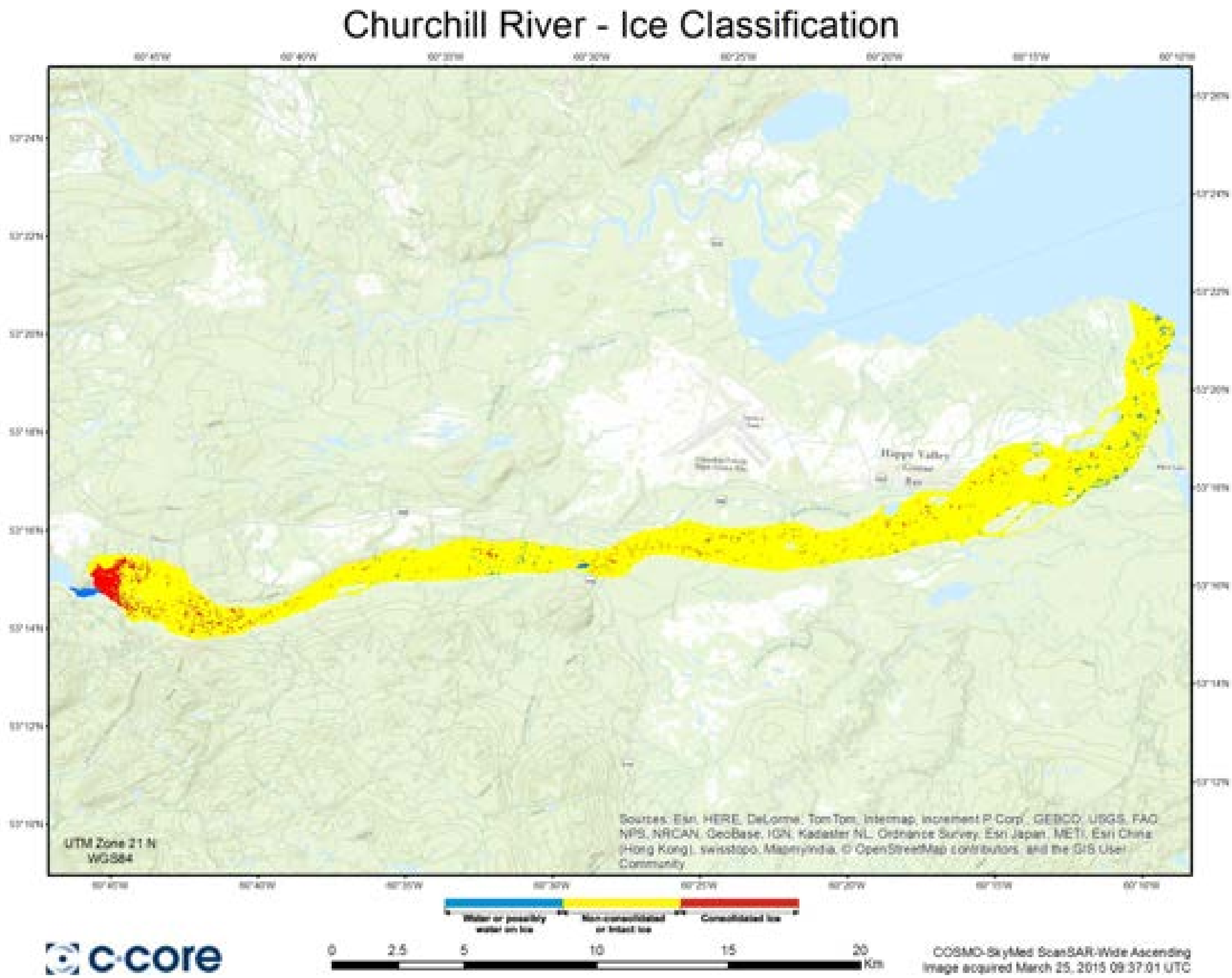
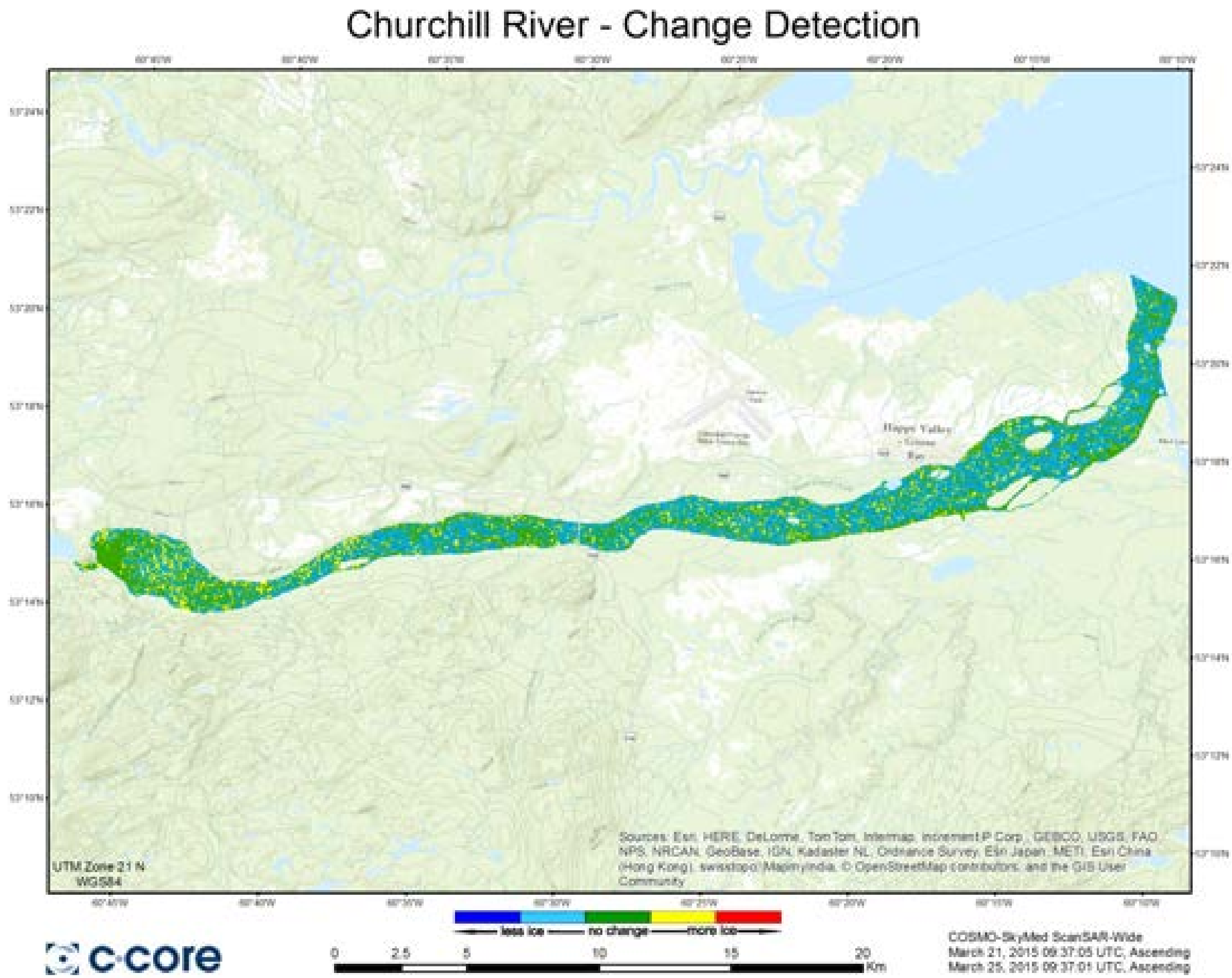
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 21, 2015 09:37:05 UTC

Churchill River - Change Detection

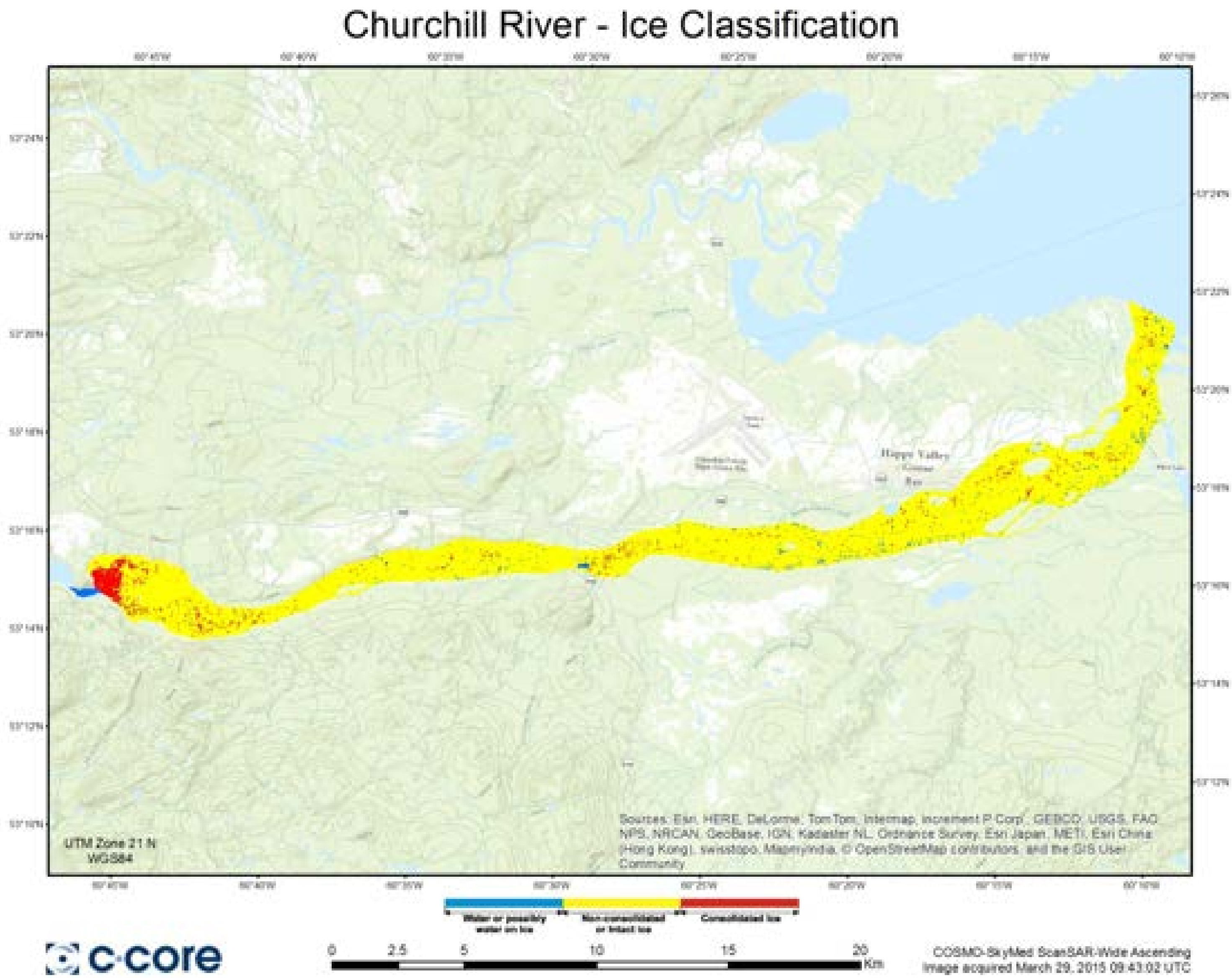


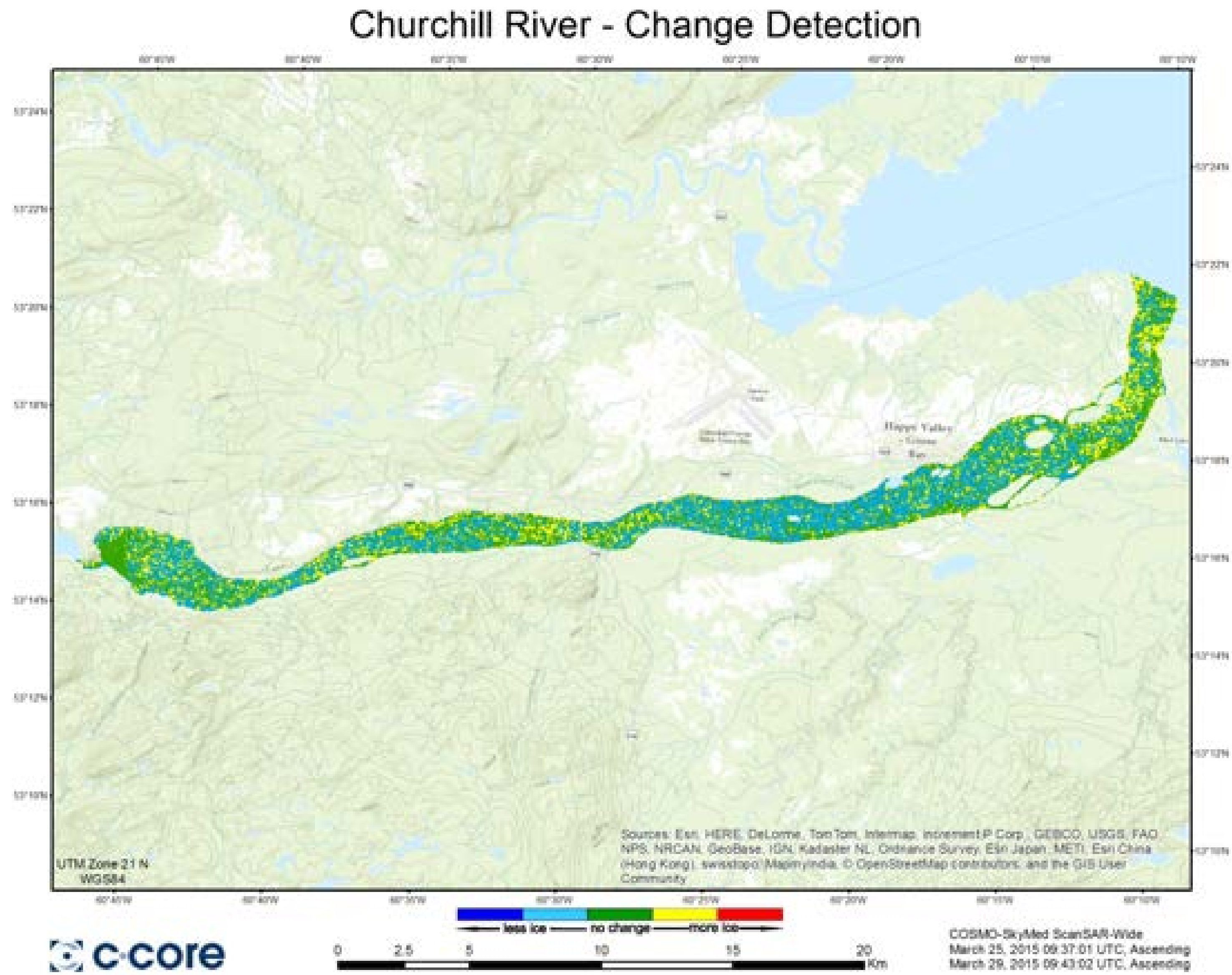

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 25, 2015 09:37:01 UTC


Churchill River - Ice Classification
Happy Valley
Goose
Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 25, 2015 09:37:01 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
c·core
COSMO-SkyMed ScanSAR-Wide
March 21, 2015 09:37:05 UTC, Ascending
March 25, 2015 09:37:01 UTC, Ascending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 29, 2015 09:43:02 UTC


Churchill River - Ice Classification
Happy Valley
Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
c·core
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired March 29, 2015 09:43:02 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
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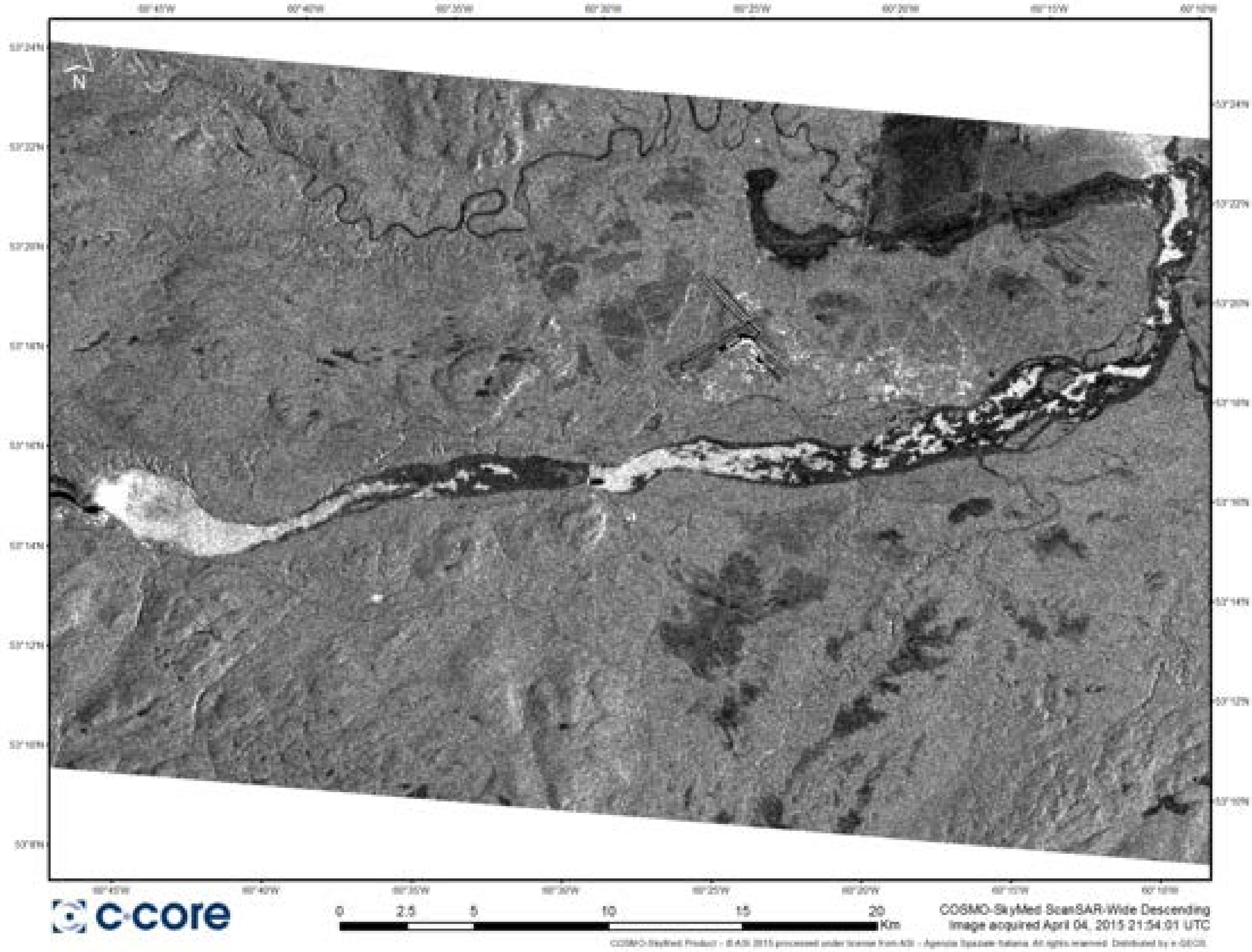
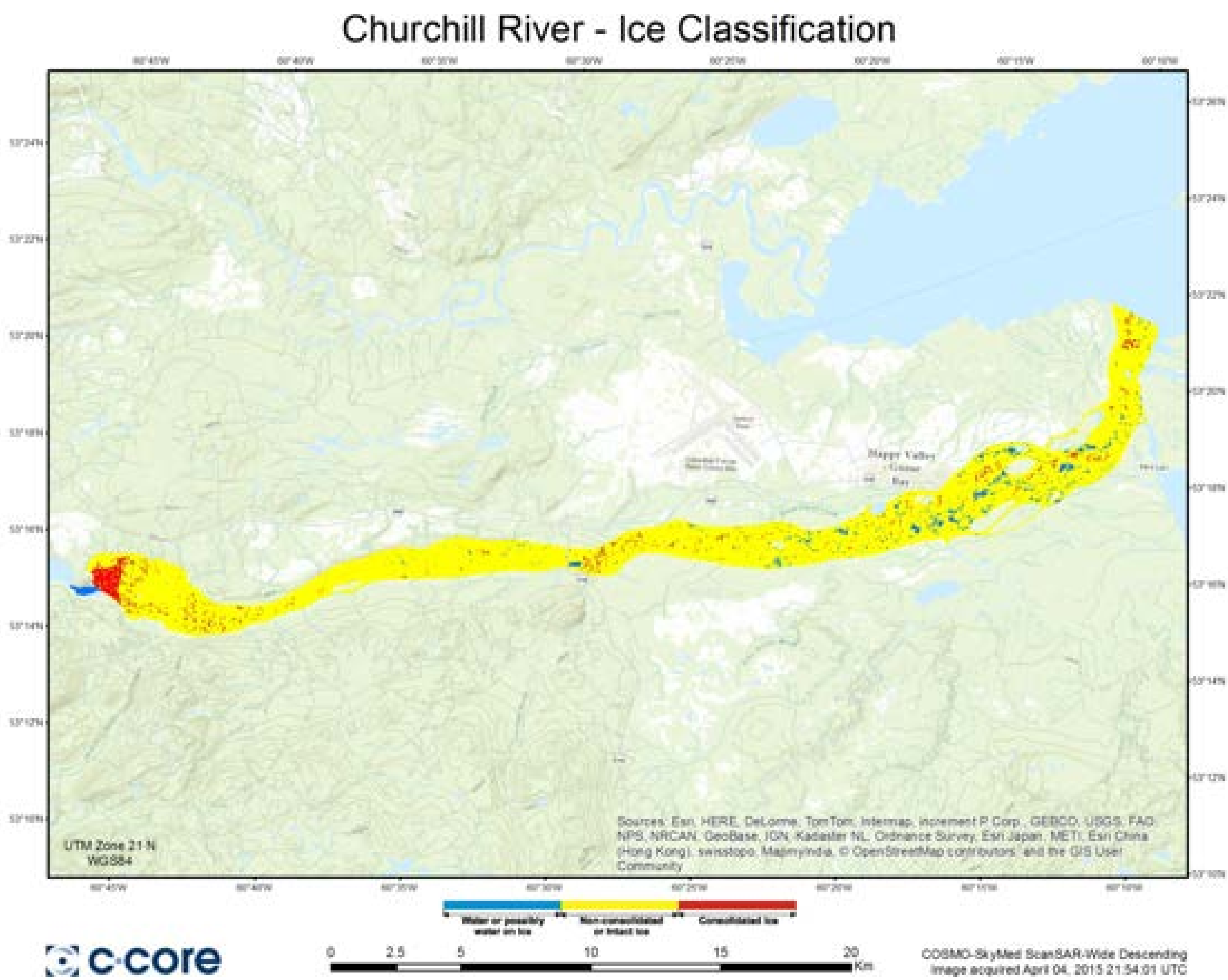
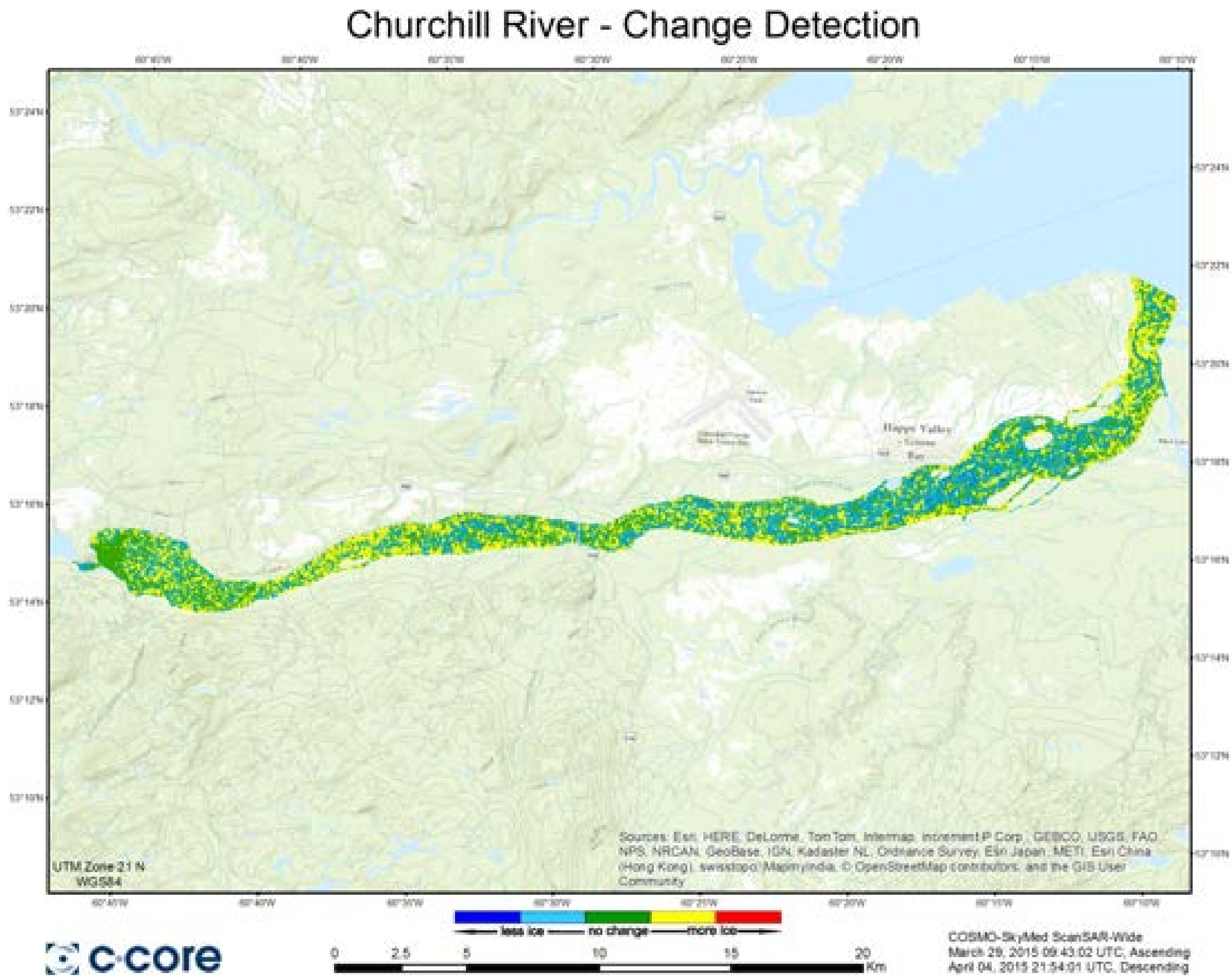
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
March 25, 2015 09:37:01 UTC, Ascending
March 29, 2015 09:43:02 UTC, Ascending

Churchill River - Ice Cover




Churchill River - Ice Classification
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired April 04, 2015 21:54:01 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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2.5
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10
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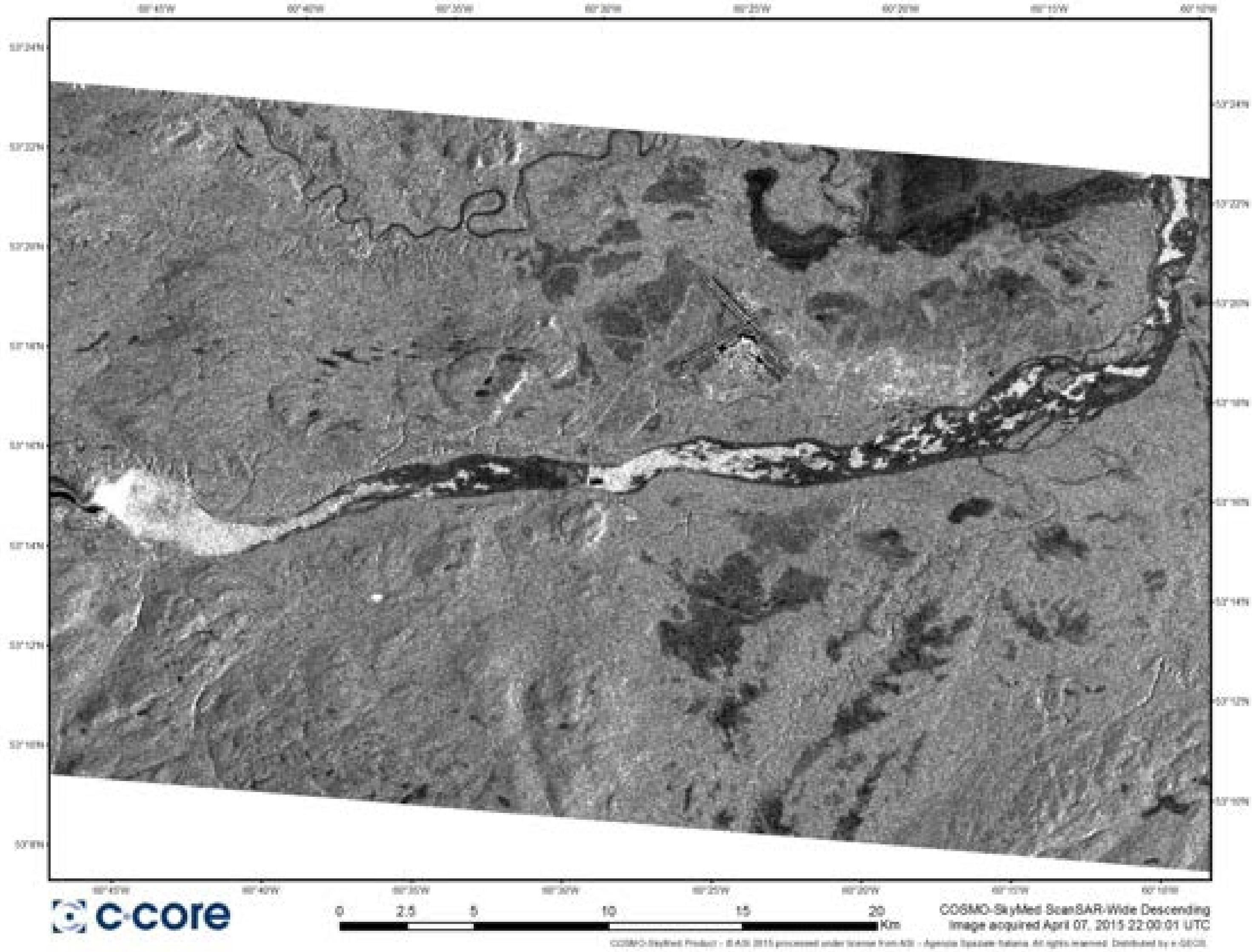
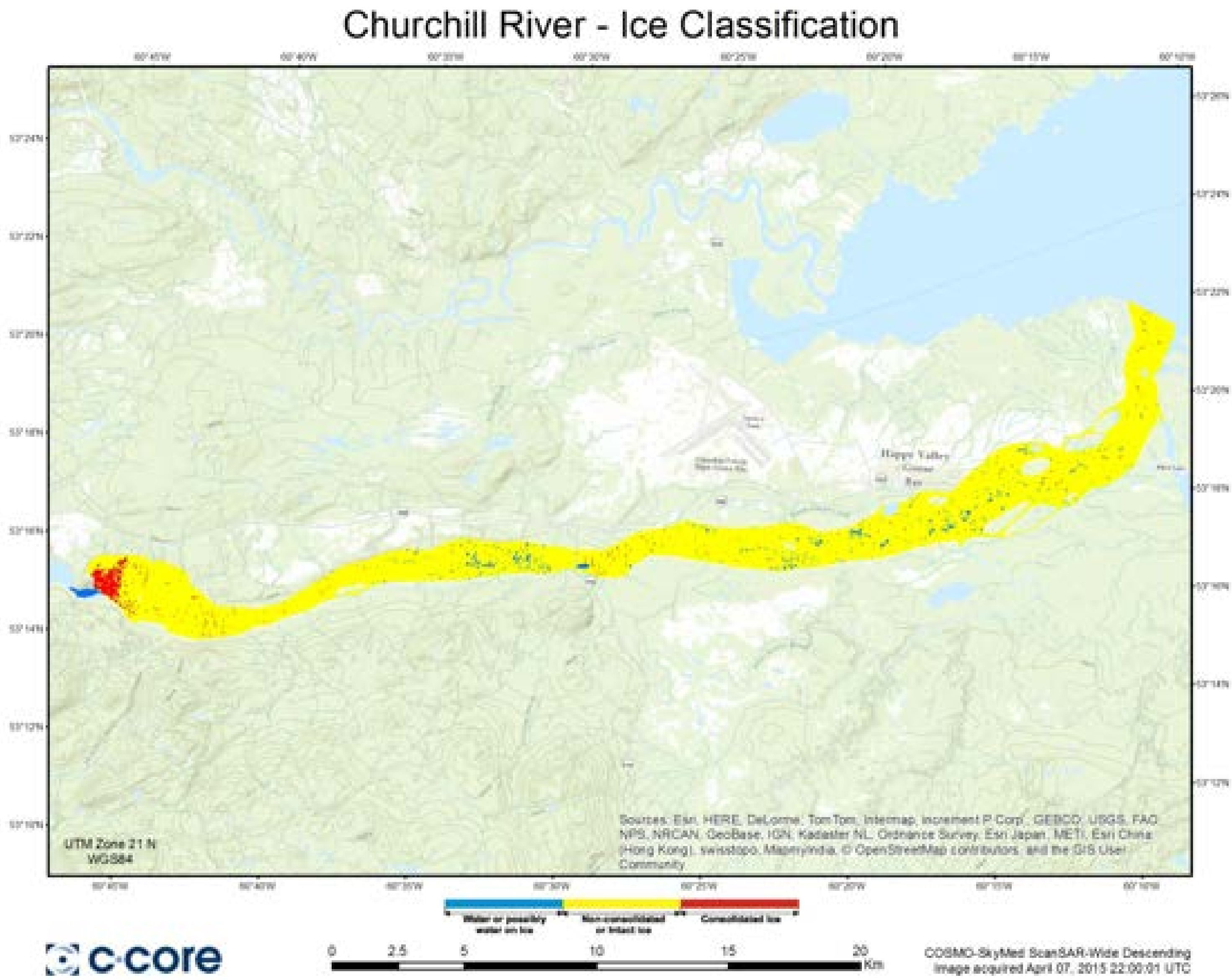
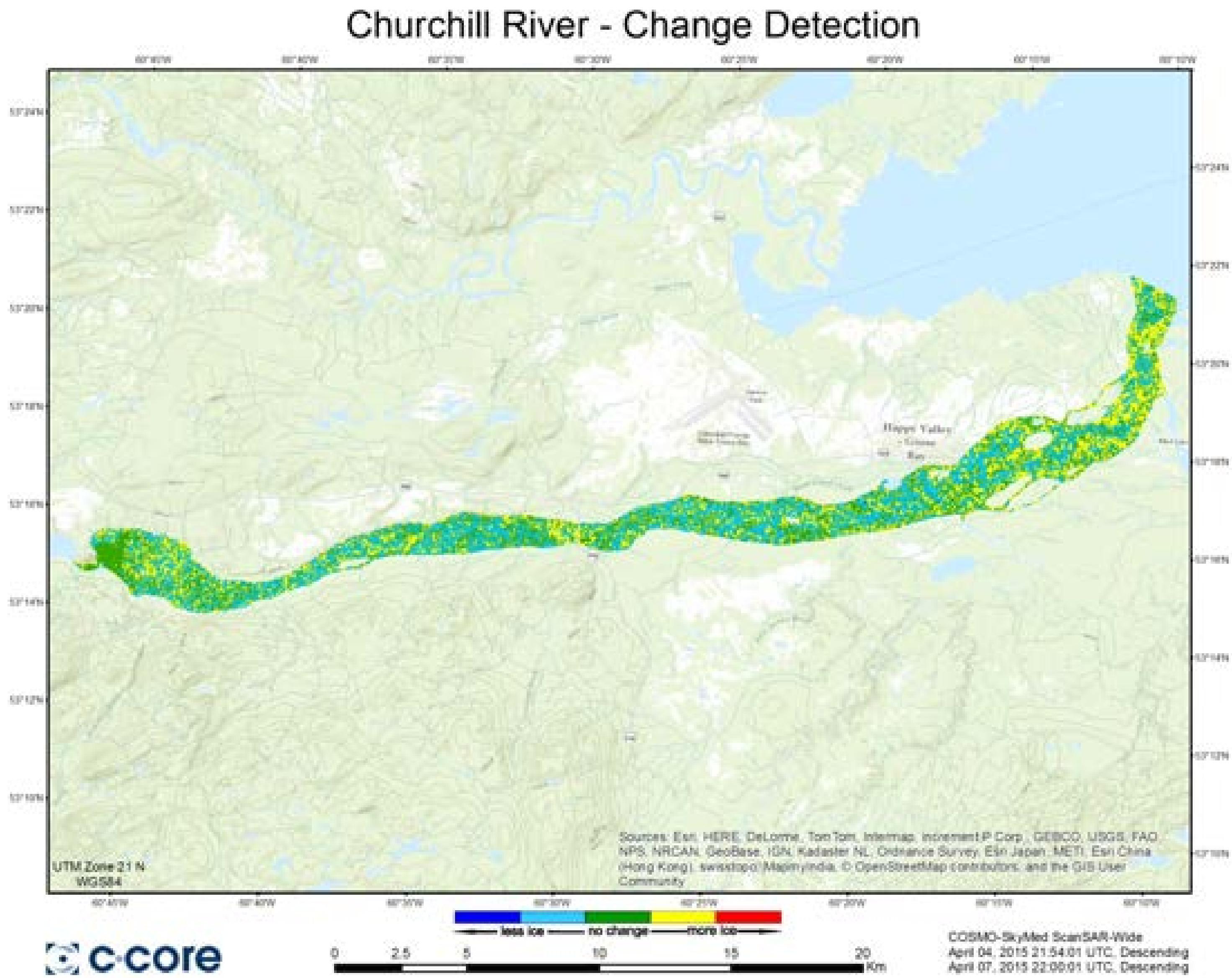
20
Km
COSMO-SkyMed ScanSAR-Wide
March 29, 2015 09:43:02 UTC, Ascending
April 04, 2015 21:54:01 UTC, Descending

Churchill River - Ice Cover




Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or intact ice
Consolidated ice
c-core
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Descending
Image acquired April 07, 2015 22:00:01 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
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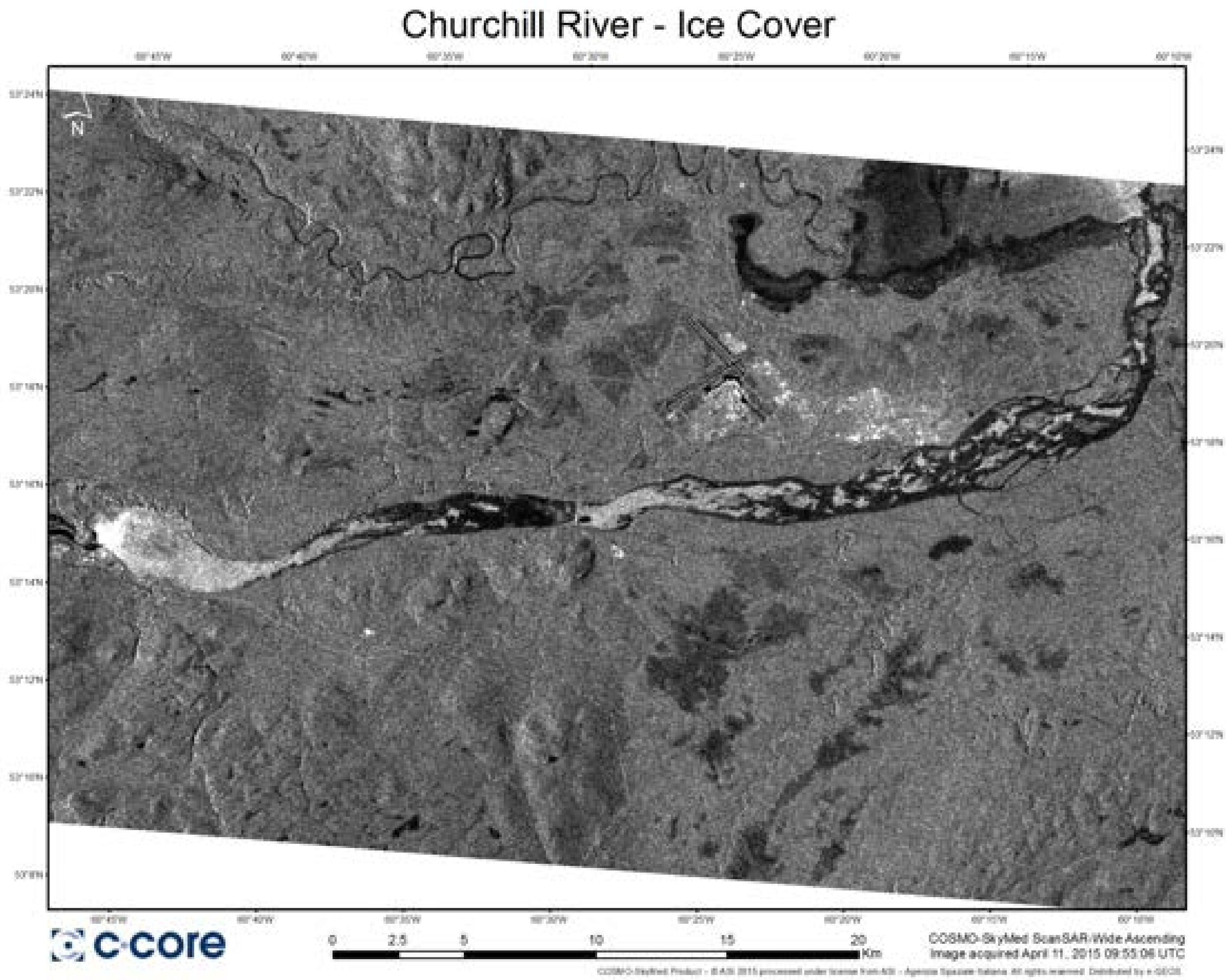
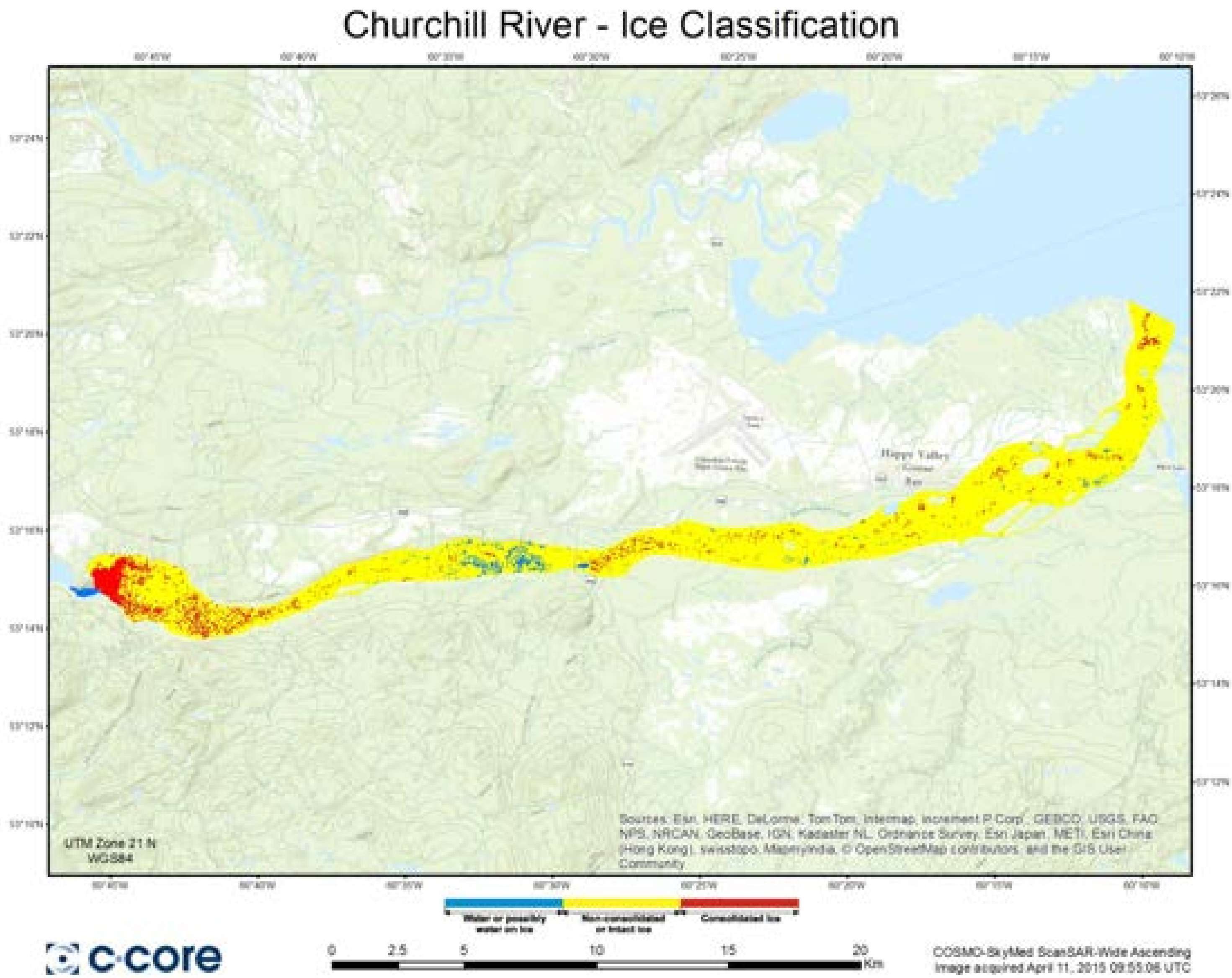
Km
COSMO-SkyMed ScanSAR-Wide
April 04, 2015 21:54:01 UTC, Descending
April 07, 2015 22:00:01 UTC, Descending


Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 11, 2015 09:55:06 UTC


Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
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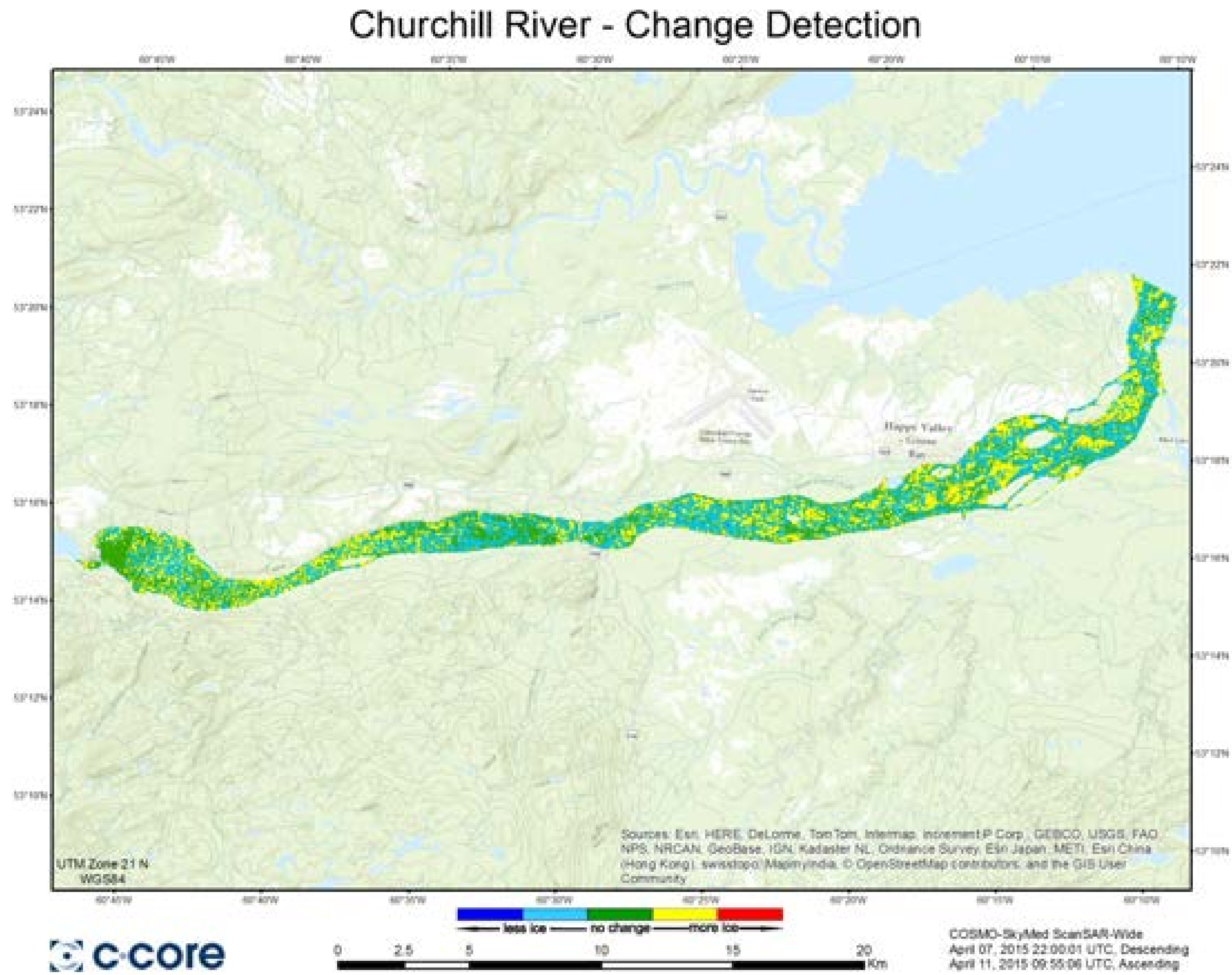
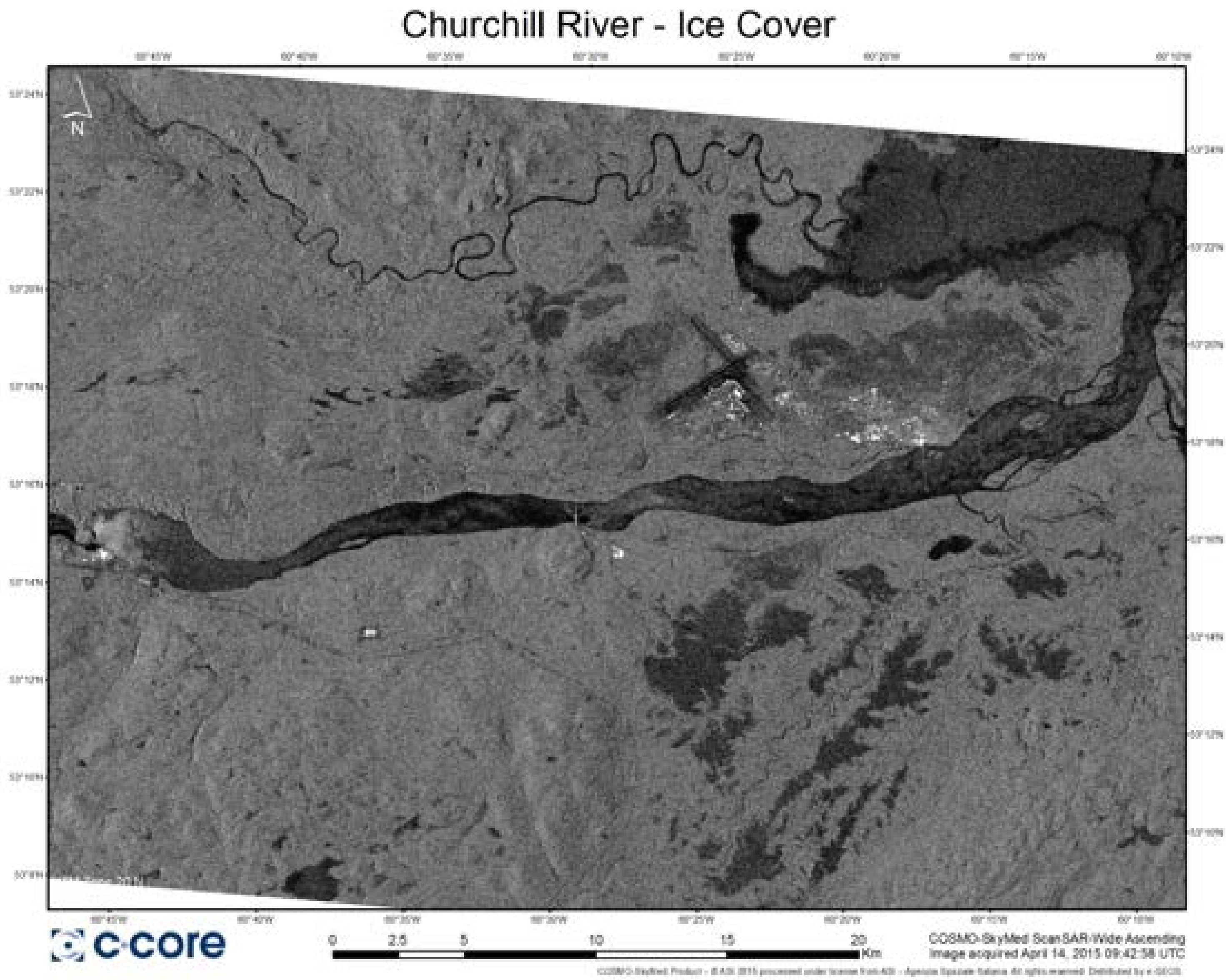
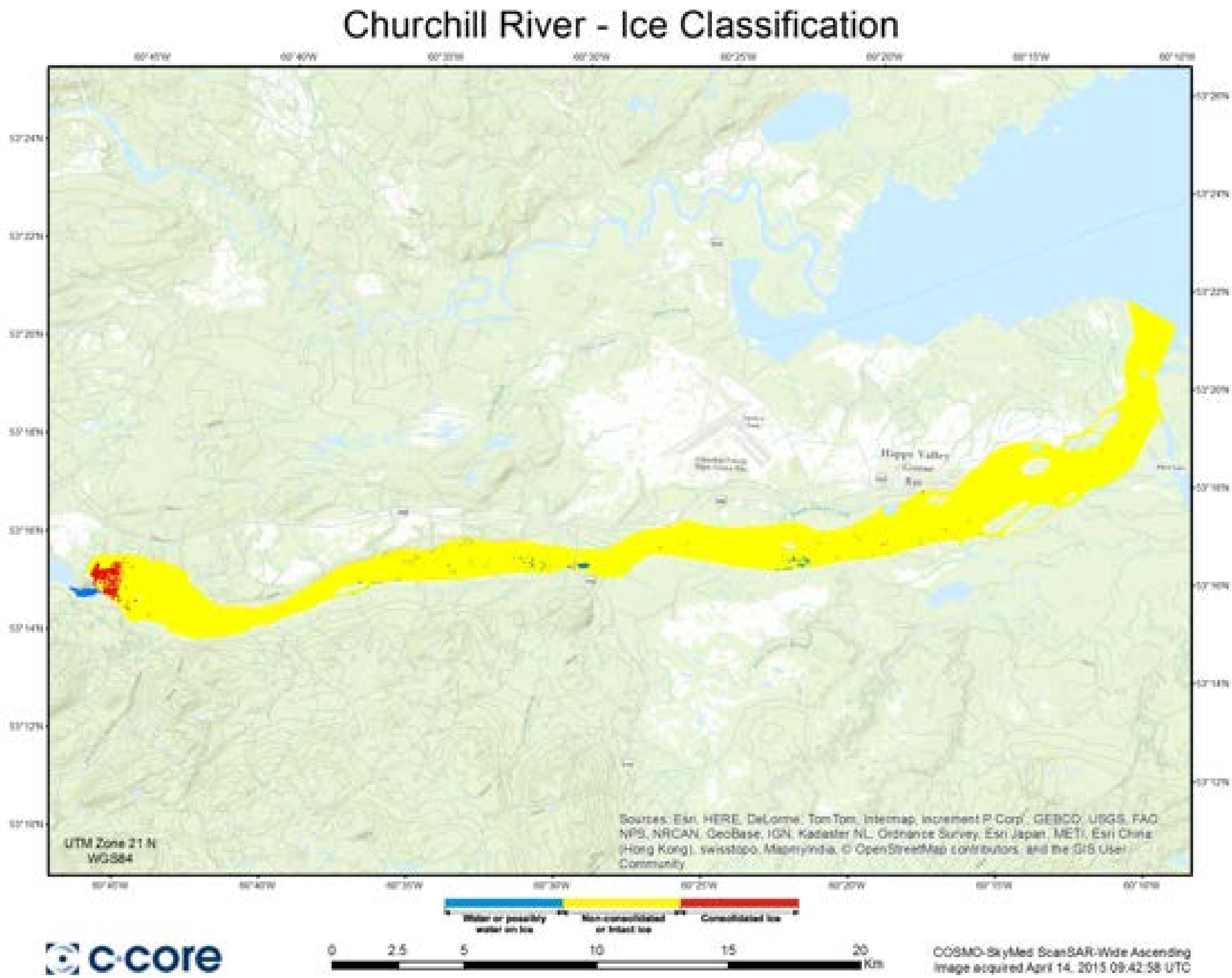
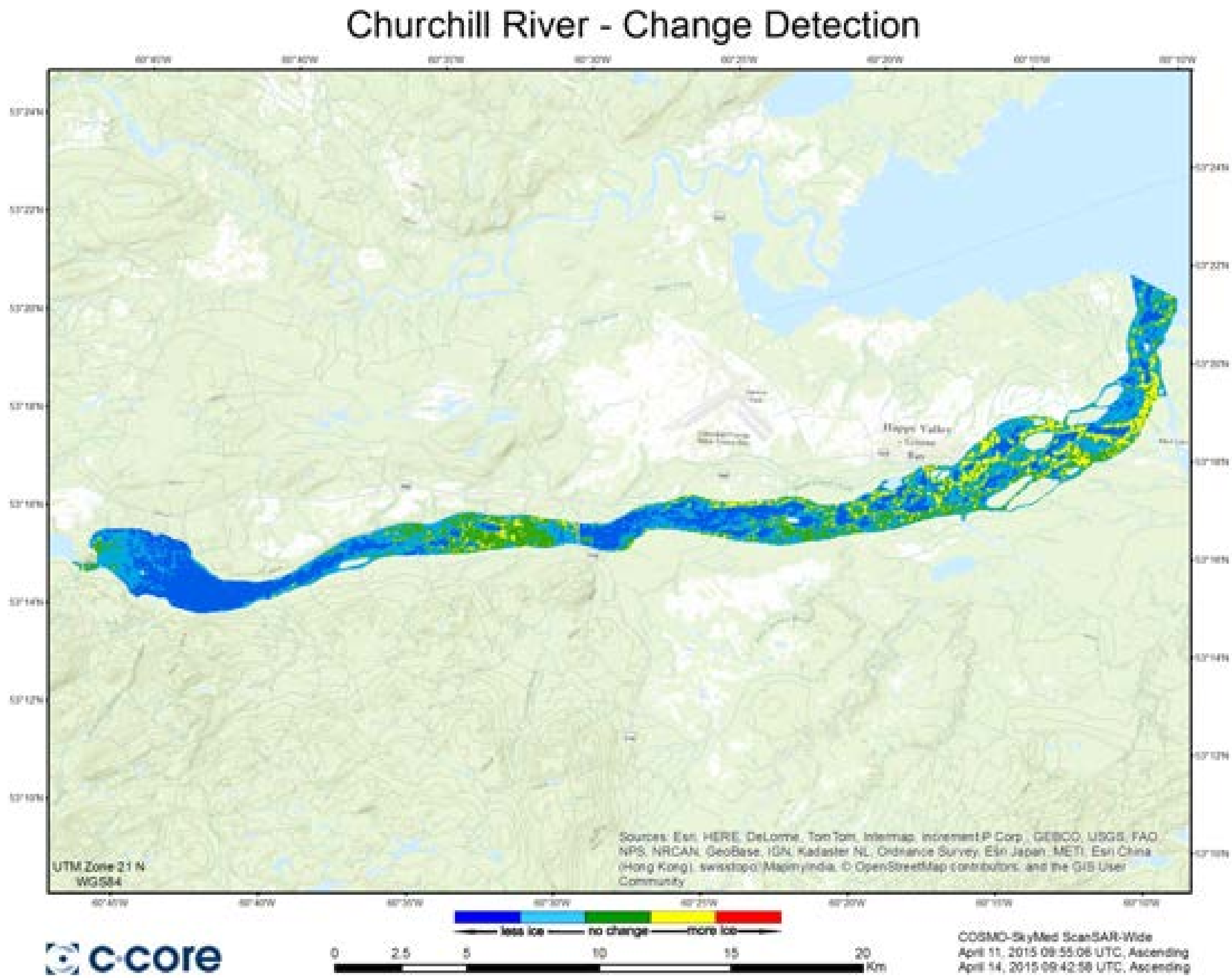
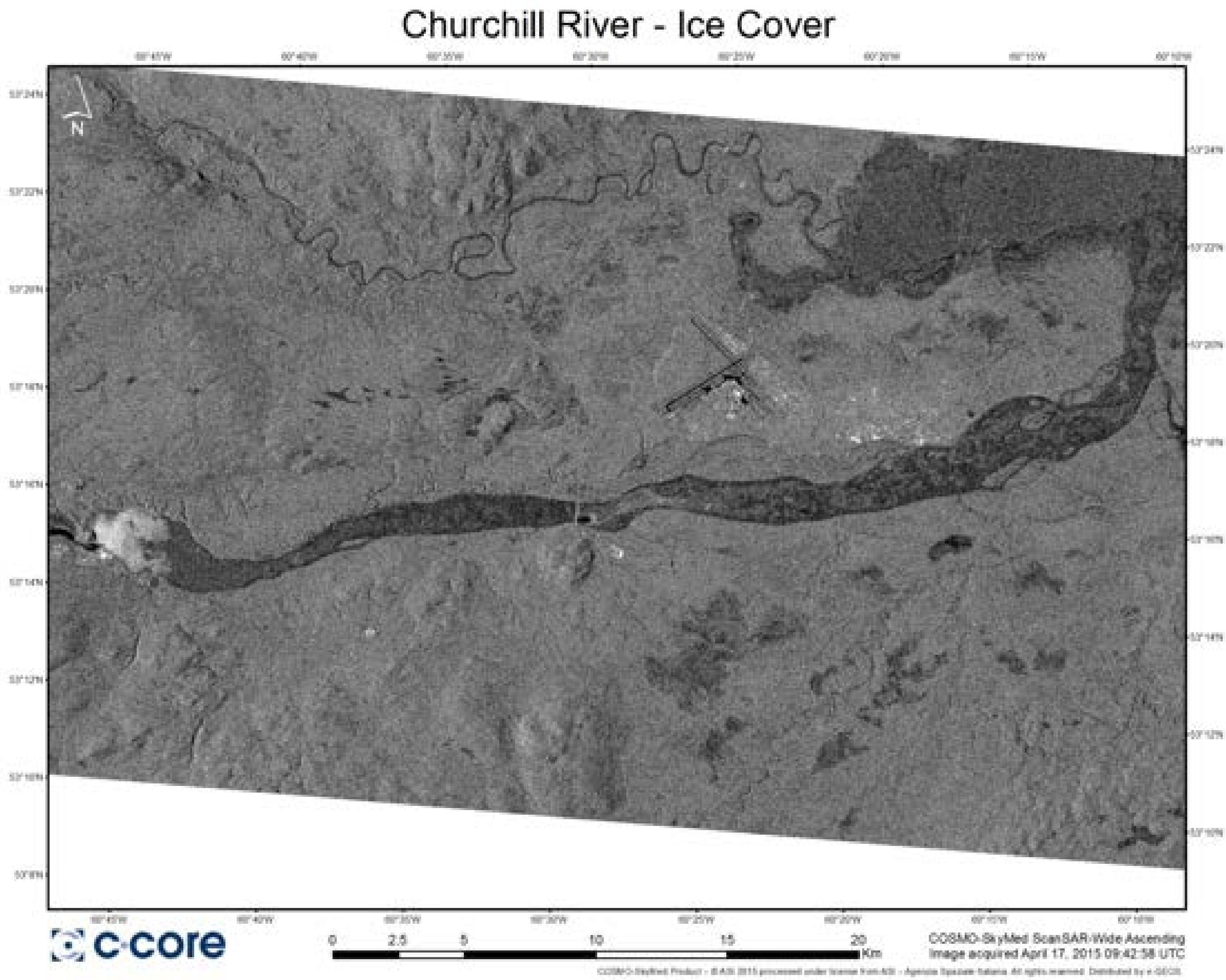
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 11, 2015 09:55:06 UTC

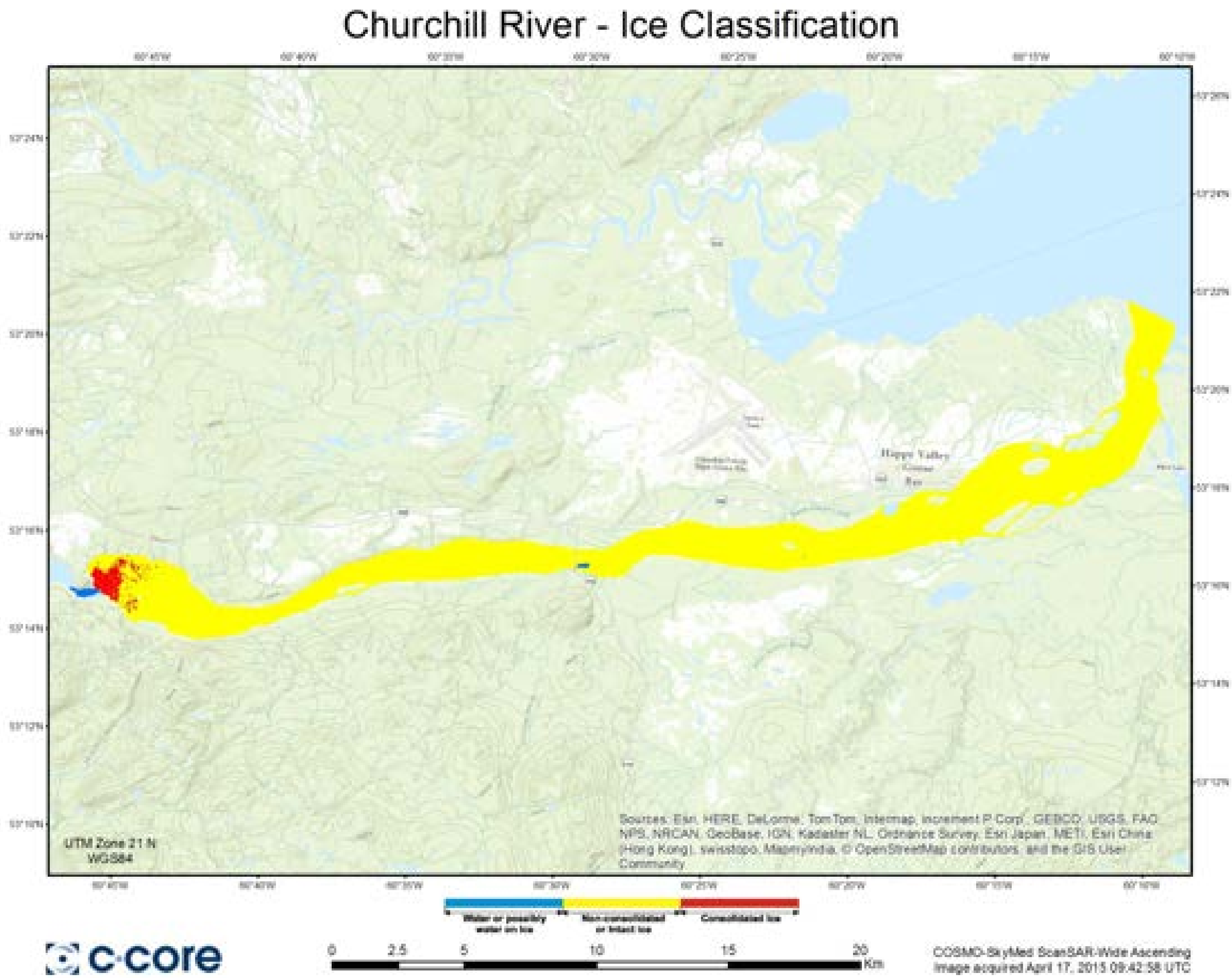

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
c·core
COSMO-SkyMed ScanSAR-Wide
April 07, 2015 22:00:01 UTC, Descending
April 11, 2015 09:55:06 UTC, Ascending

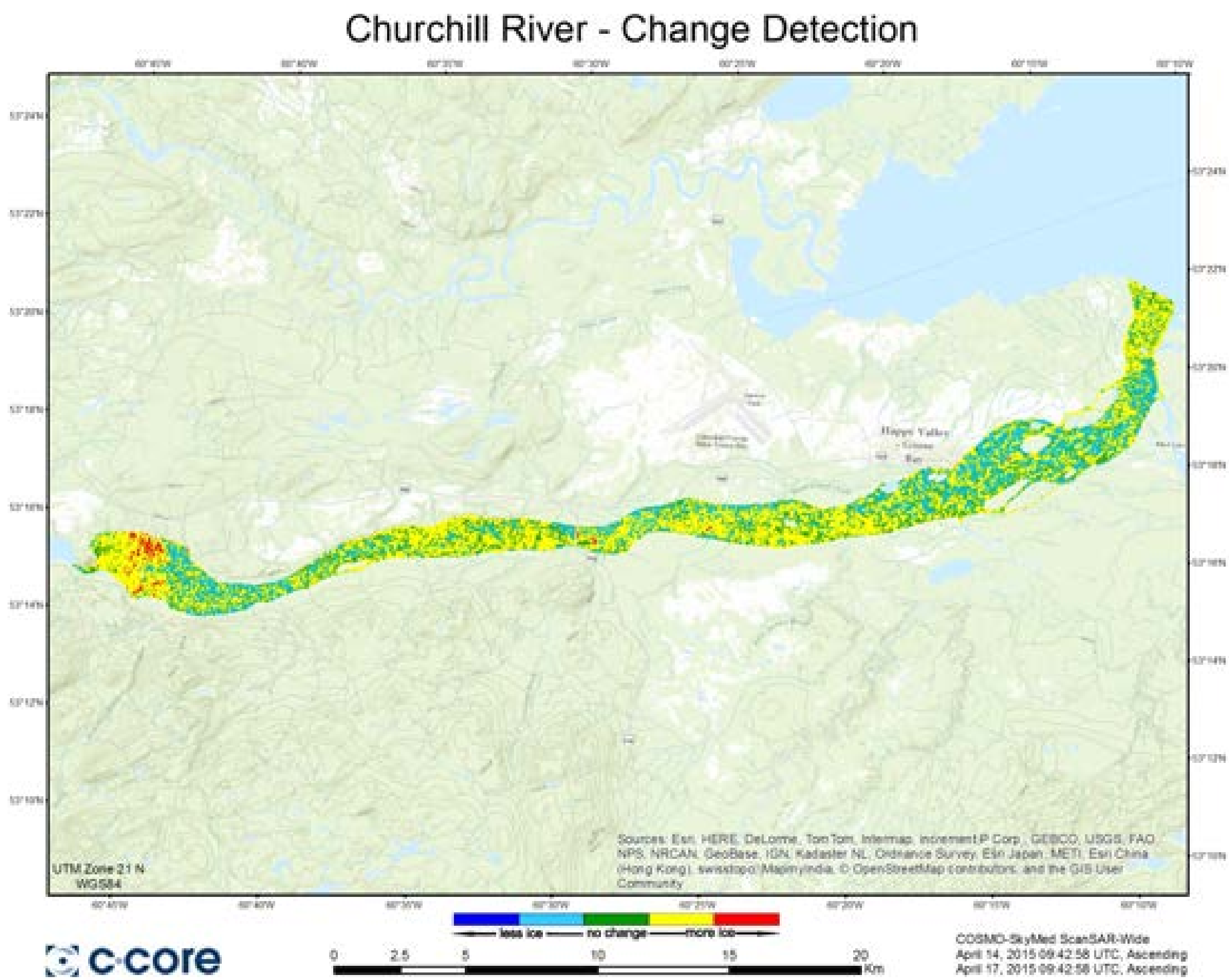

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 14, 2015 09:42:58 UTC

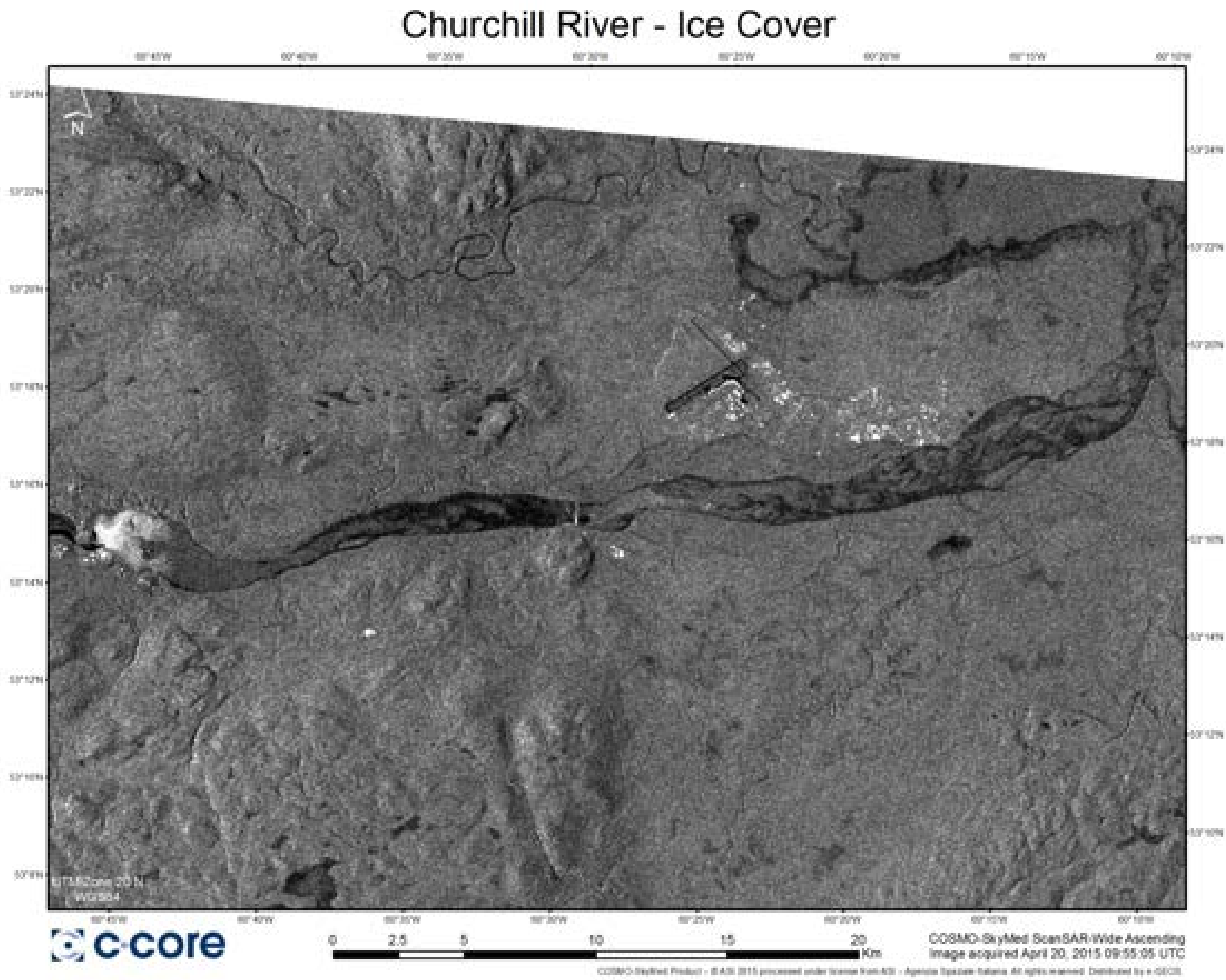

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 14, 2015 09:42:58 UTC


Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
April 11, 2015 09:55:06 UTC, Ascending
April 14, 2015 09:42:58 UTC, Ascending

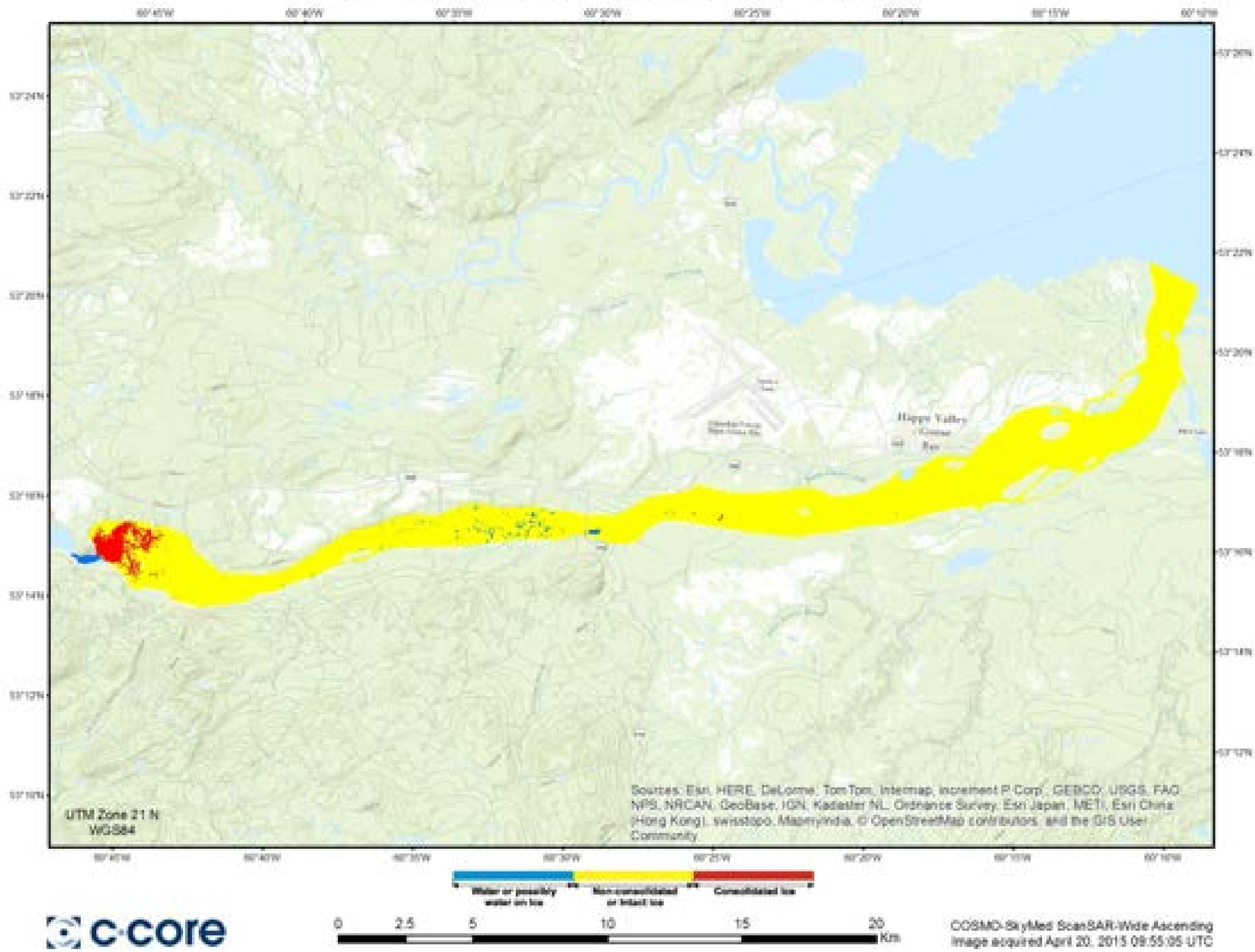

Churchill River - Ice Cover
N
c-core
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 17, 2015 09:42:58 UTC

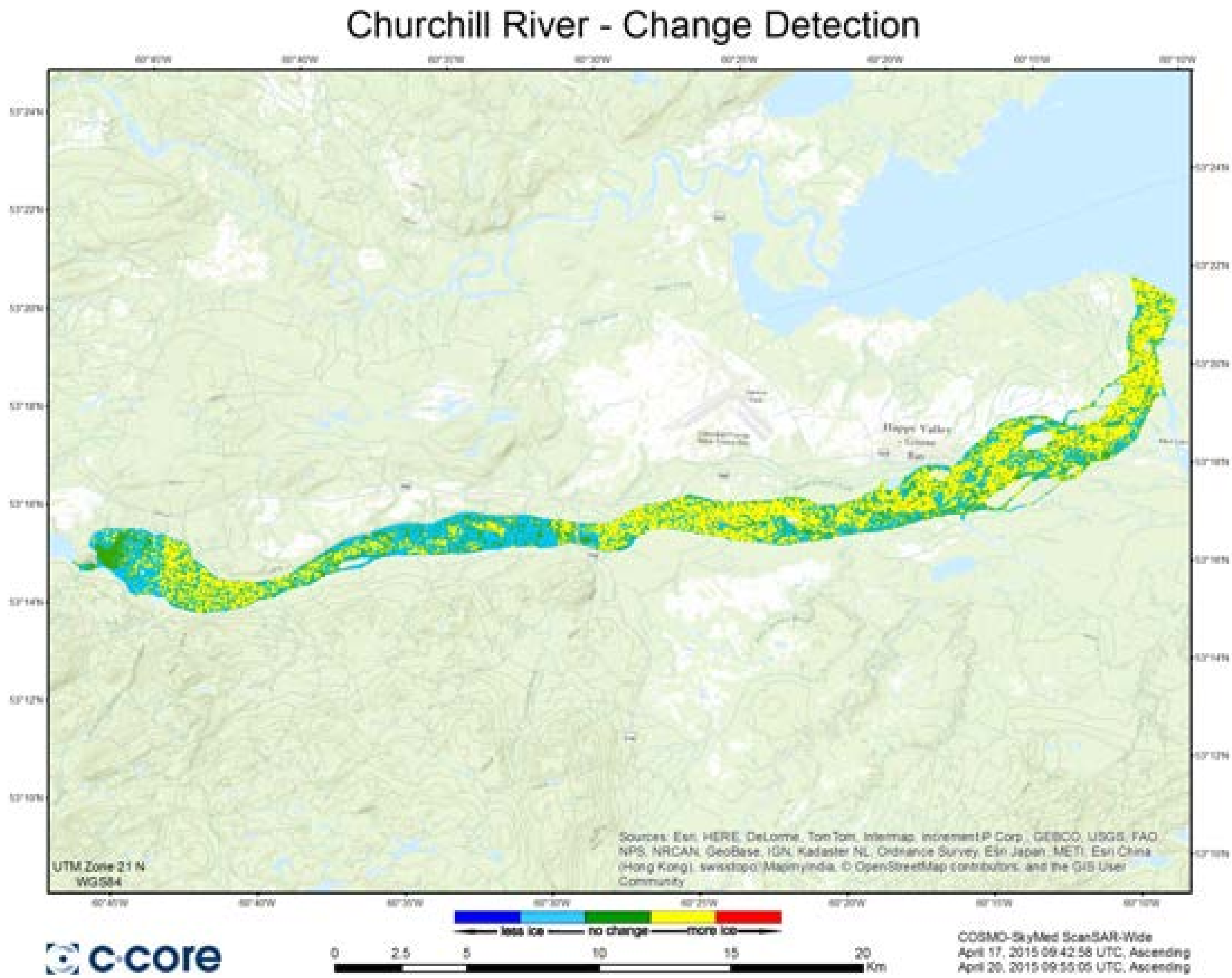

Churchill River - Ice Classification
Happy Valley-Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 17, 2015 09:42:58 UTC

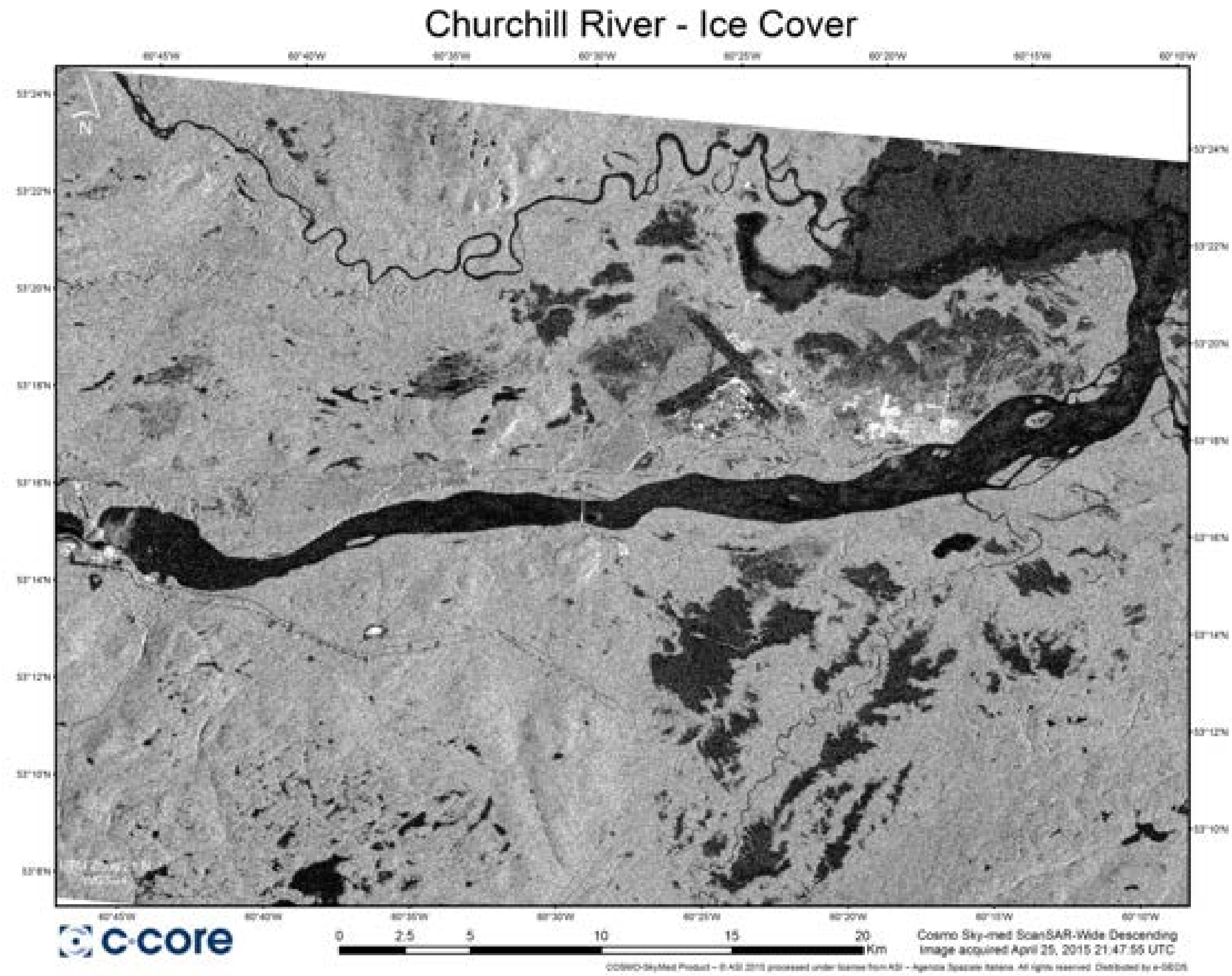

Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
April 14, 2015 09:42:58 UTC, Ascending
April 17, 2015 09:42:58 UTC, Ascending

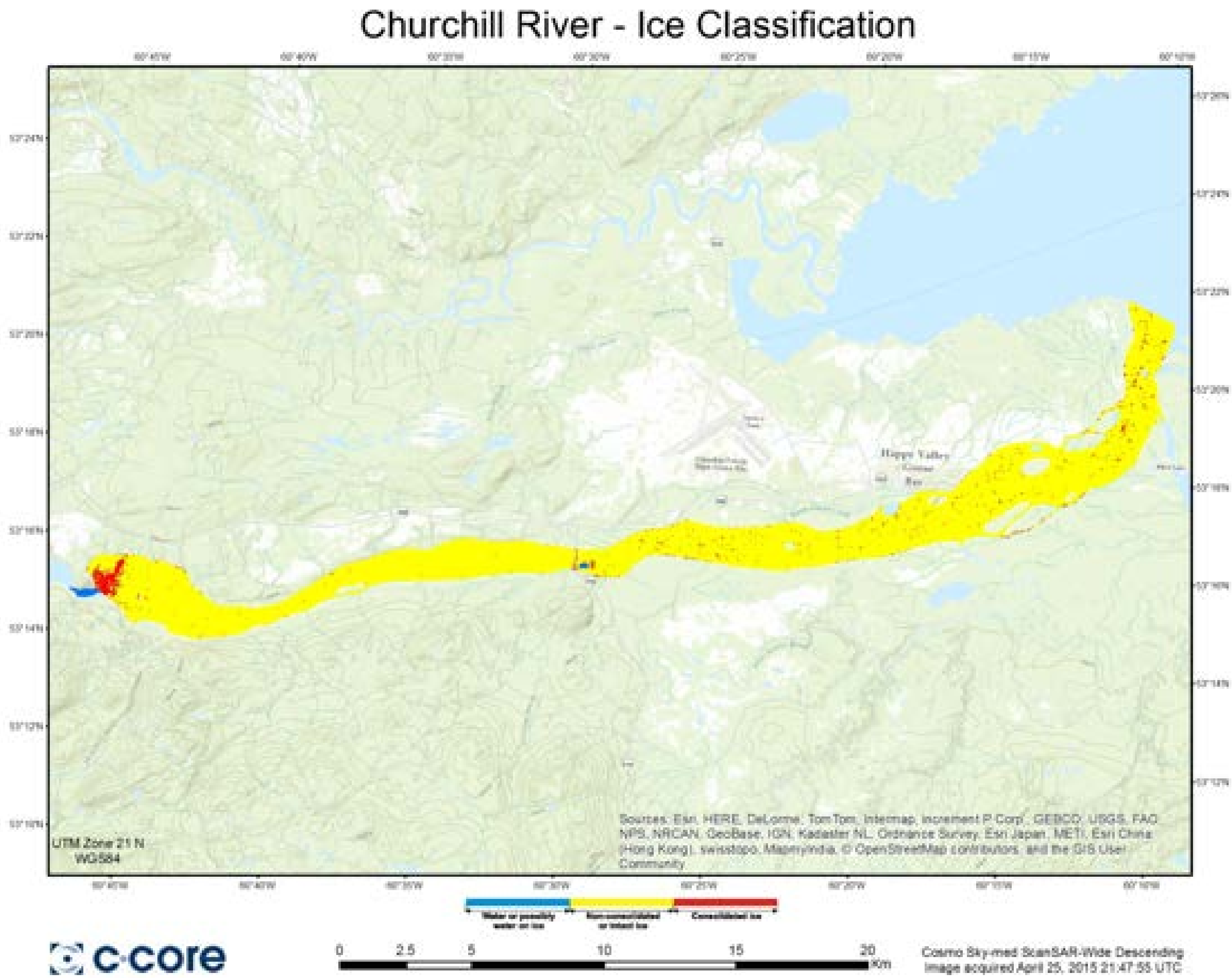

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired April 20, 2015 09:55:05 UTC

Churchill River - Ice Classification

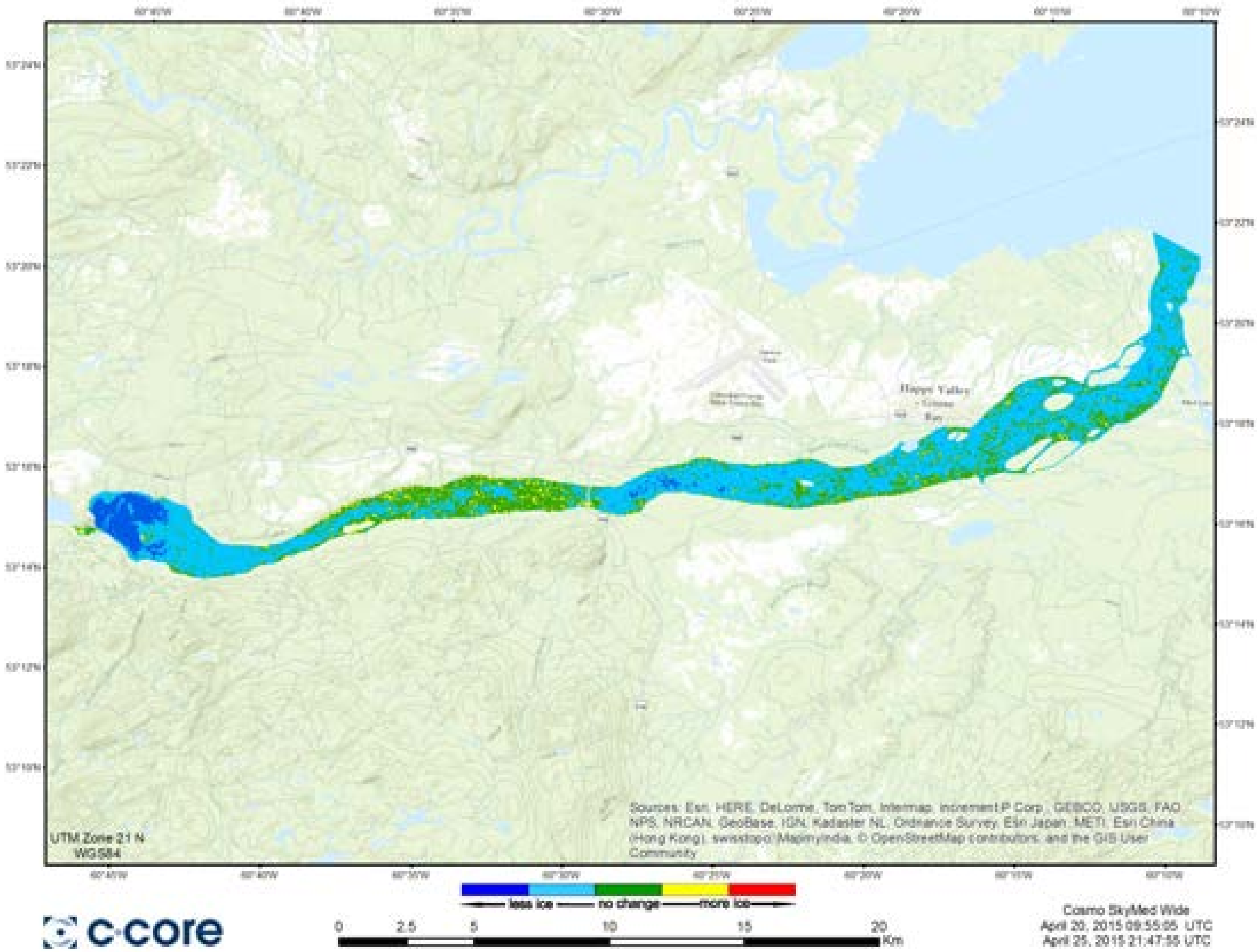



Churchill River - Change Detection
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide
April 17, 2015 09:42:58 UTC, Ascending
April 20, 2015 09:55:05 UTC, Ascending

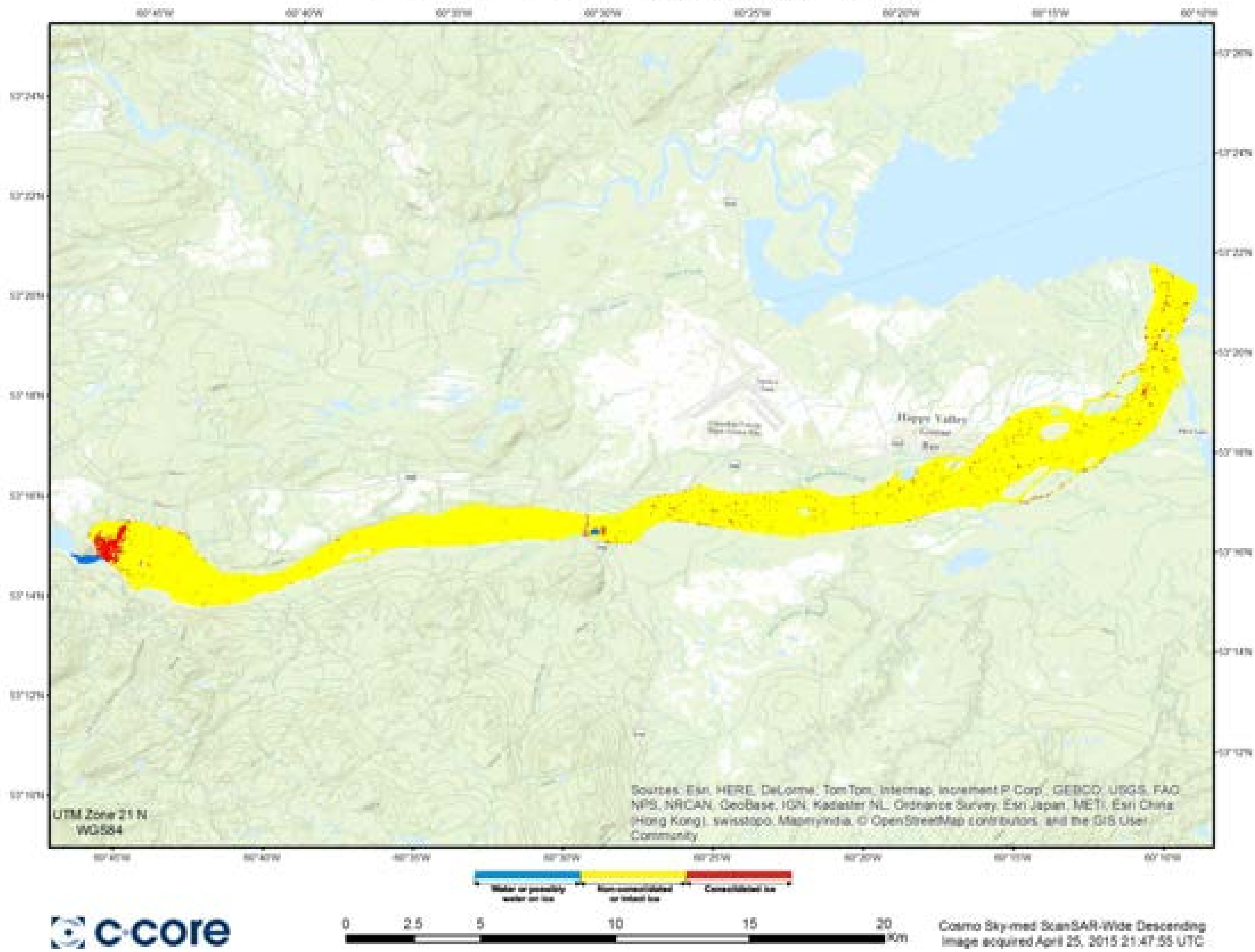

Churchill River - Ice Cover
c-core
0 2.5 5 10 15 20 Km
Cosmo Sky-med ScanSAR-Wide Descending
Image acquired April 25, 2015 21:47:55 UTC


Churchill River - Ice Classification
Happy Valley
Goose
Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
0 2.5 5 10 15 20 Km
Cosmo Sky-med ScanSAR-Wide Descending
Image acquired April 25, 2015 21:47:55 UTC

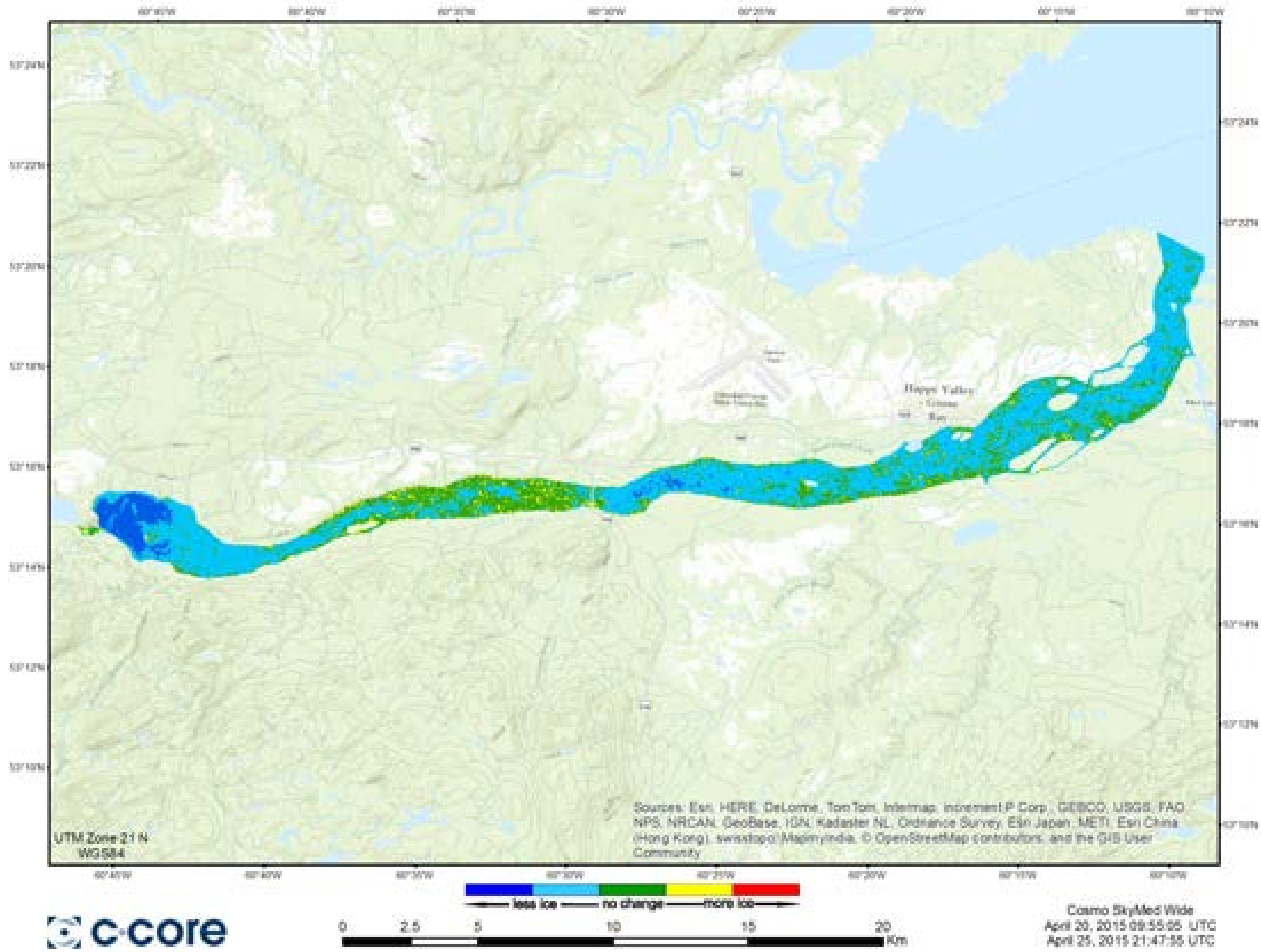
Churchill River - Change Detection

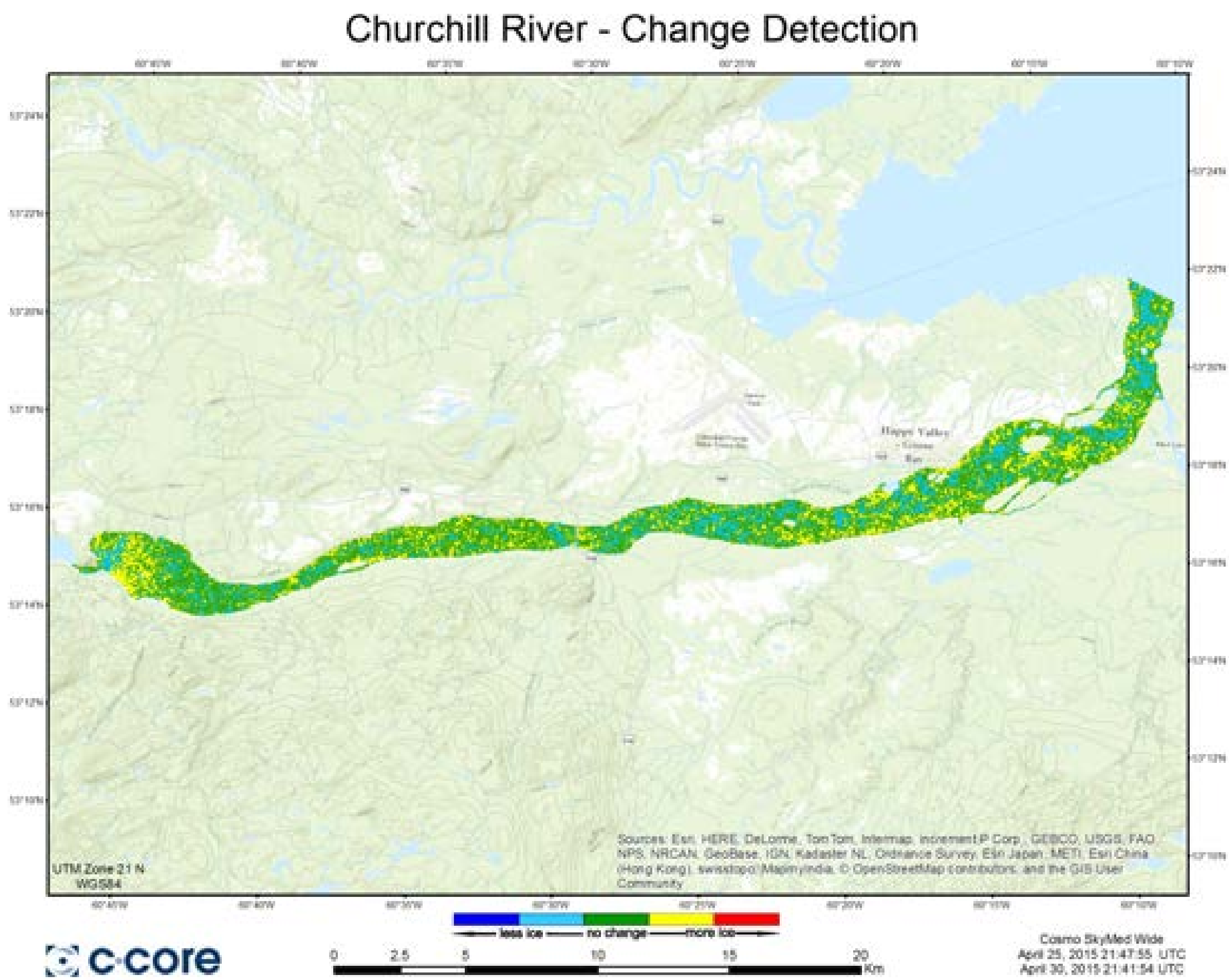


Churchill River - Ice Classification

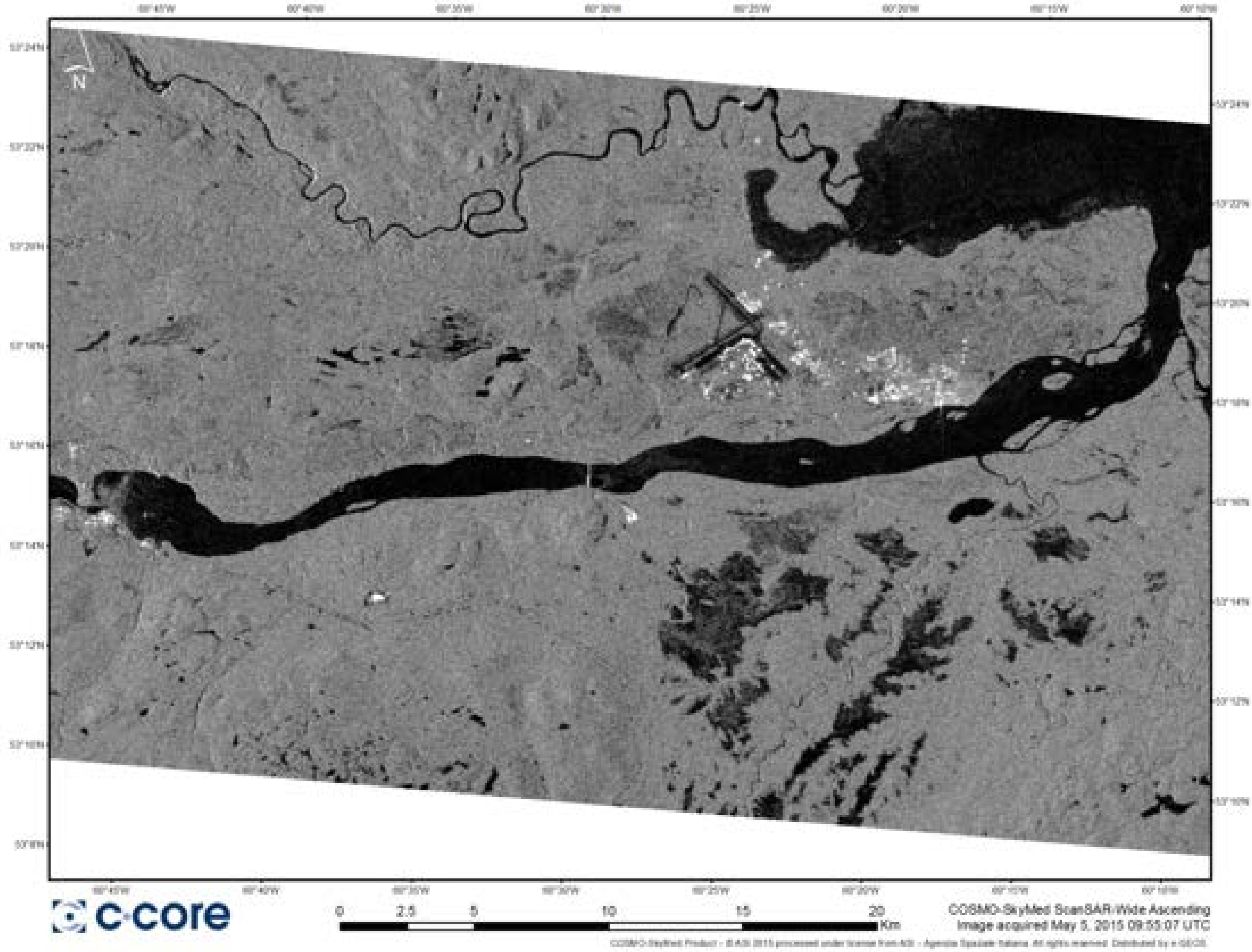


Churchill River - Change Detection

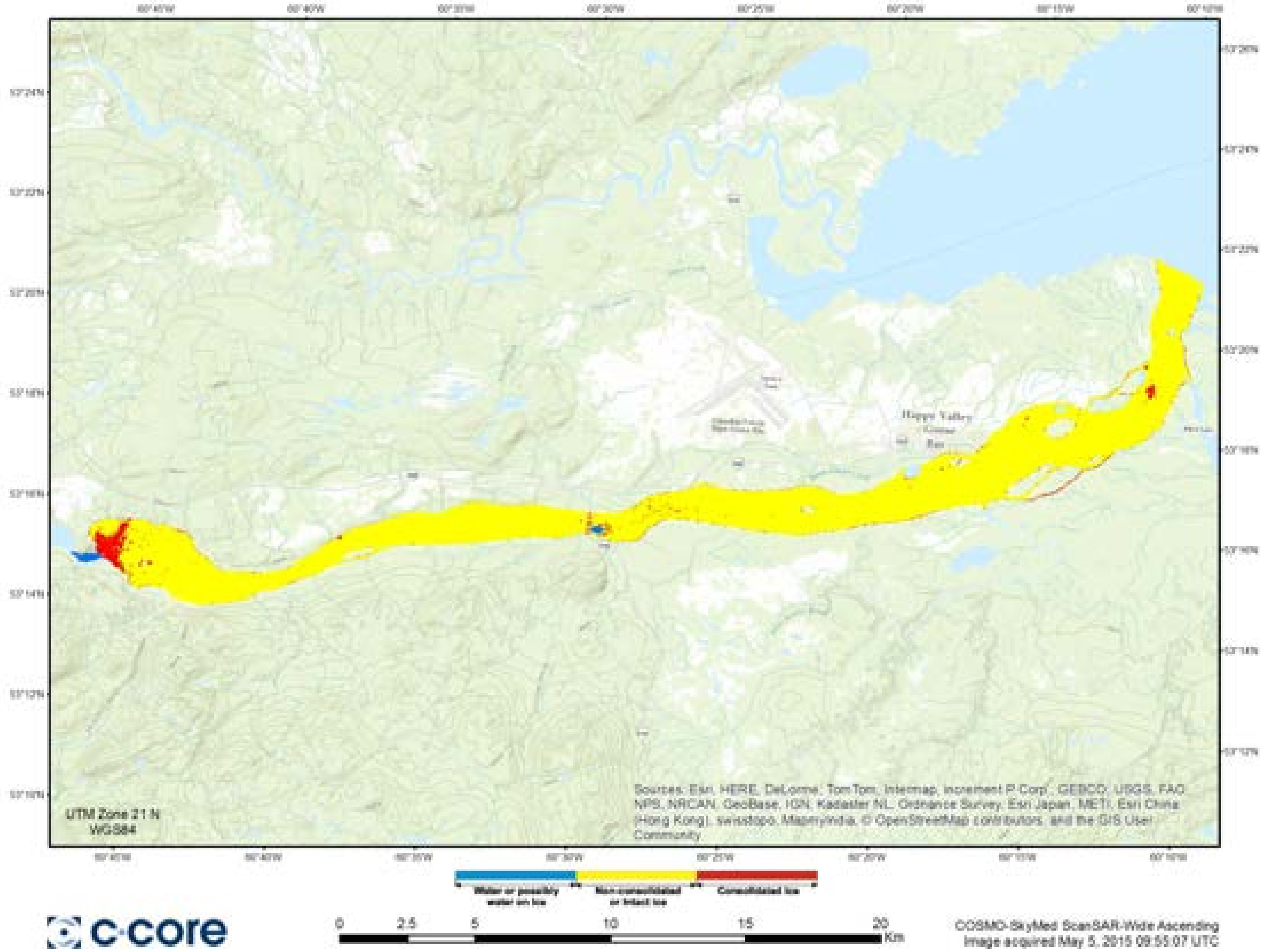


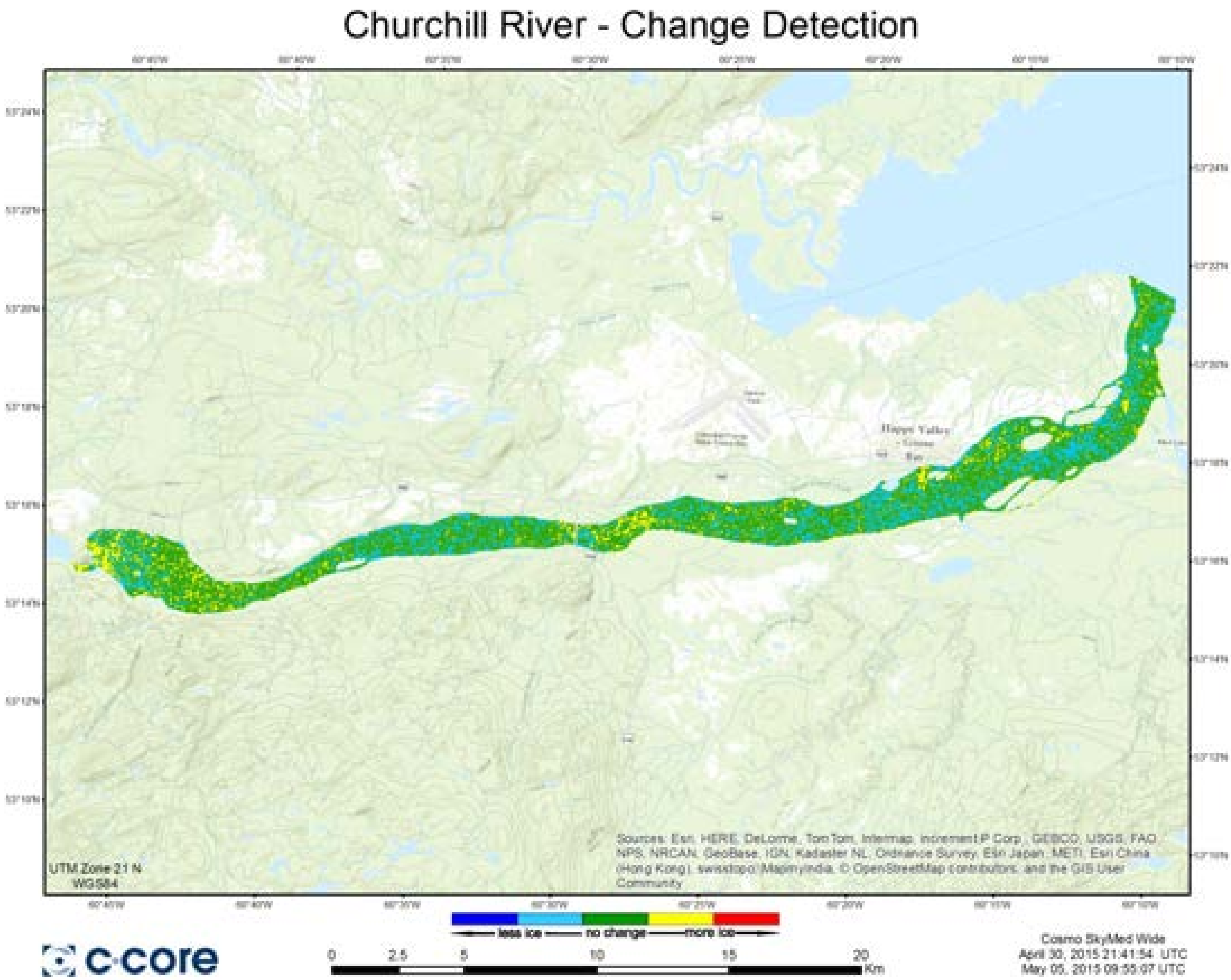

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
Cosmo SkyMed Wide
April 25, 2015 21:47:55 UTC
April 30, 2015 21:41:54 UTC

Churchill River - Ice Cover

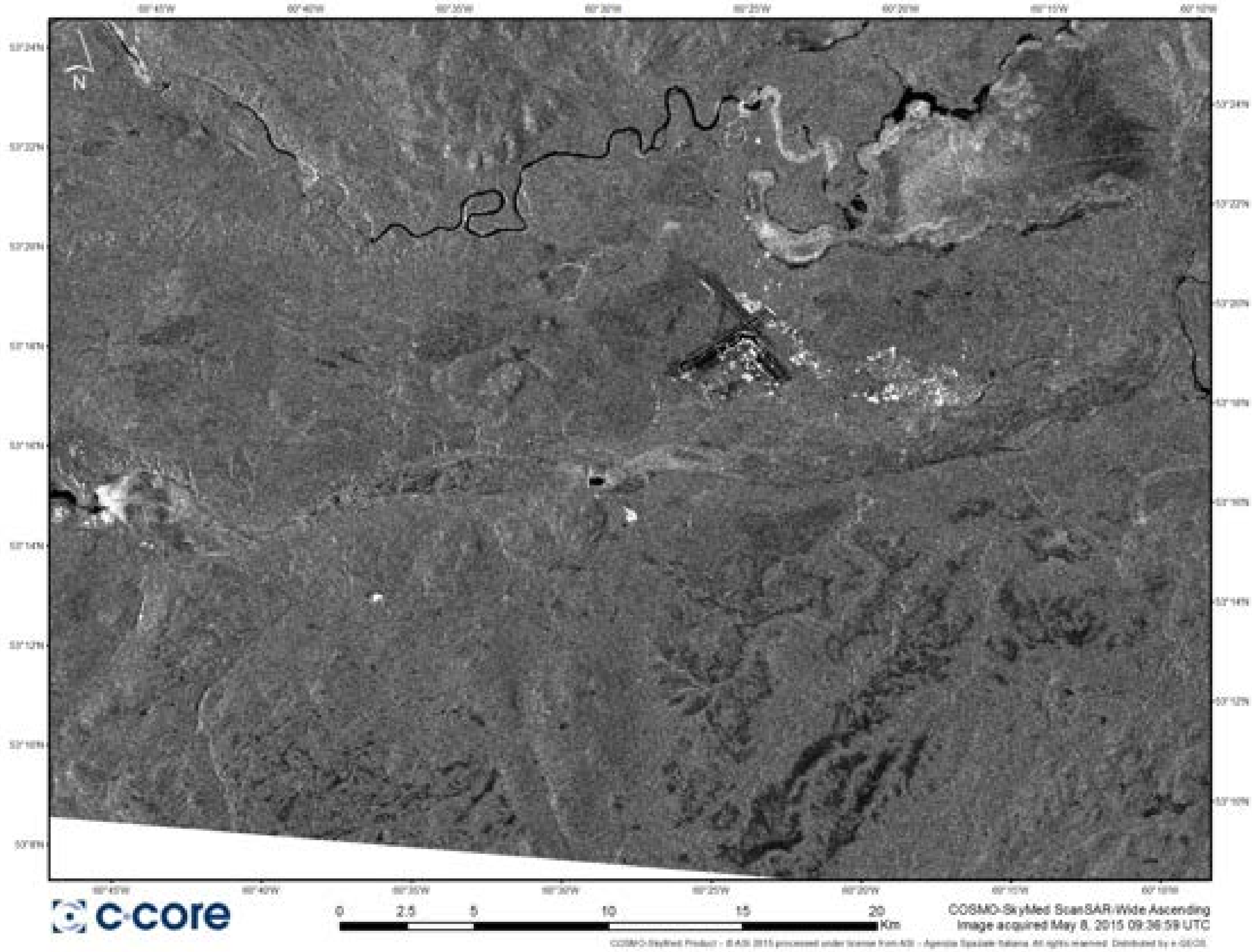


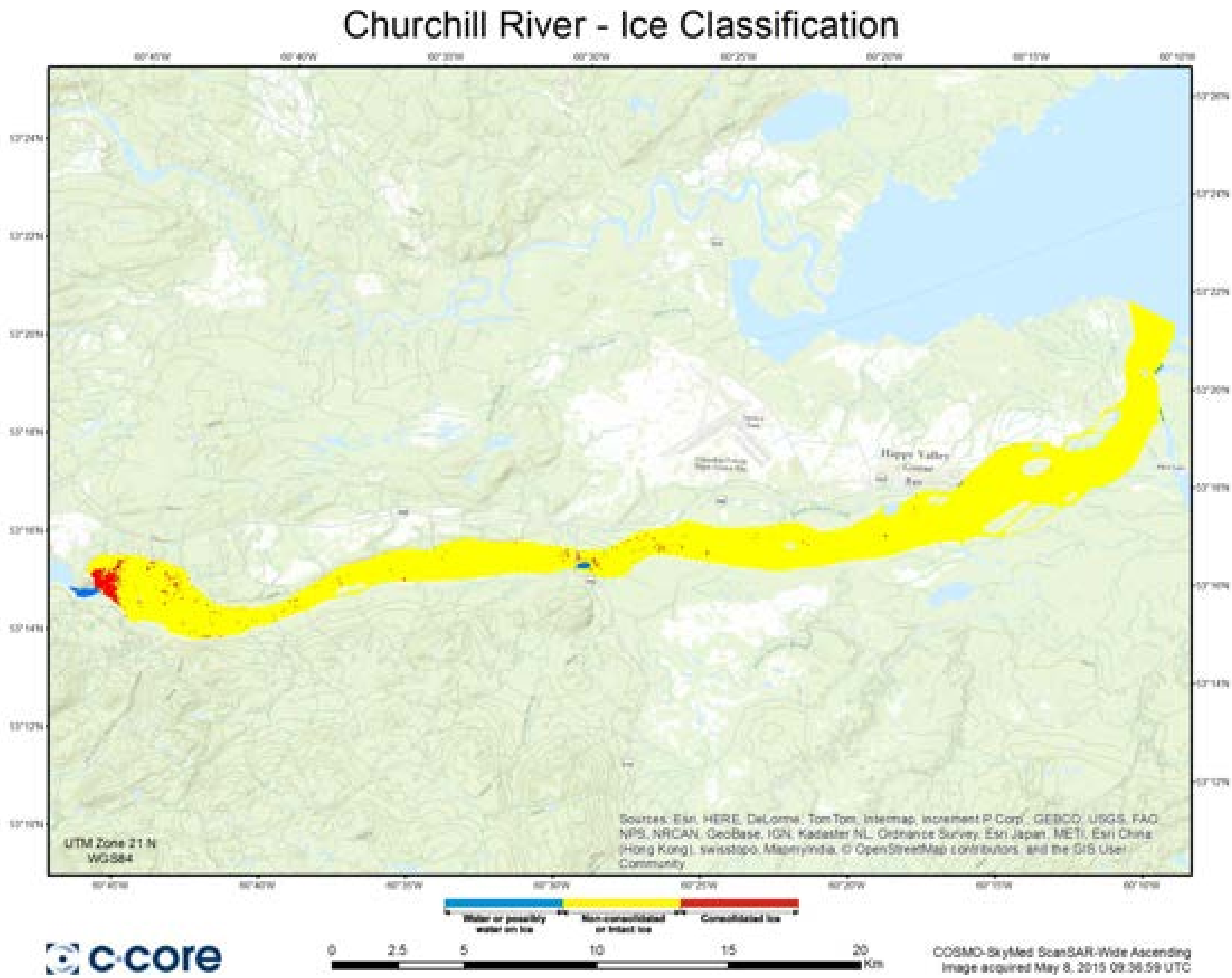
Churchill River - Ice Classification

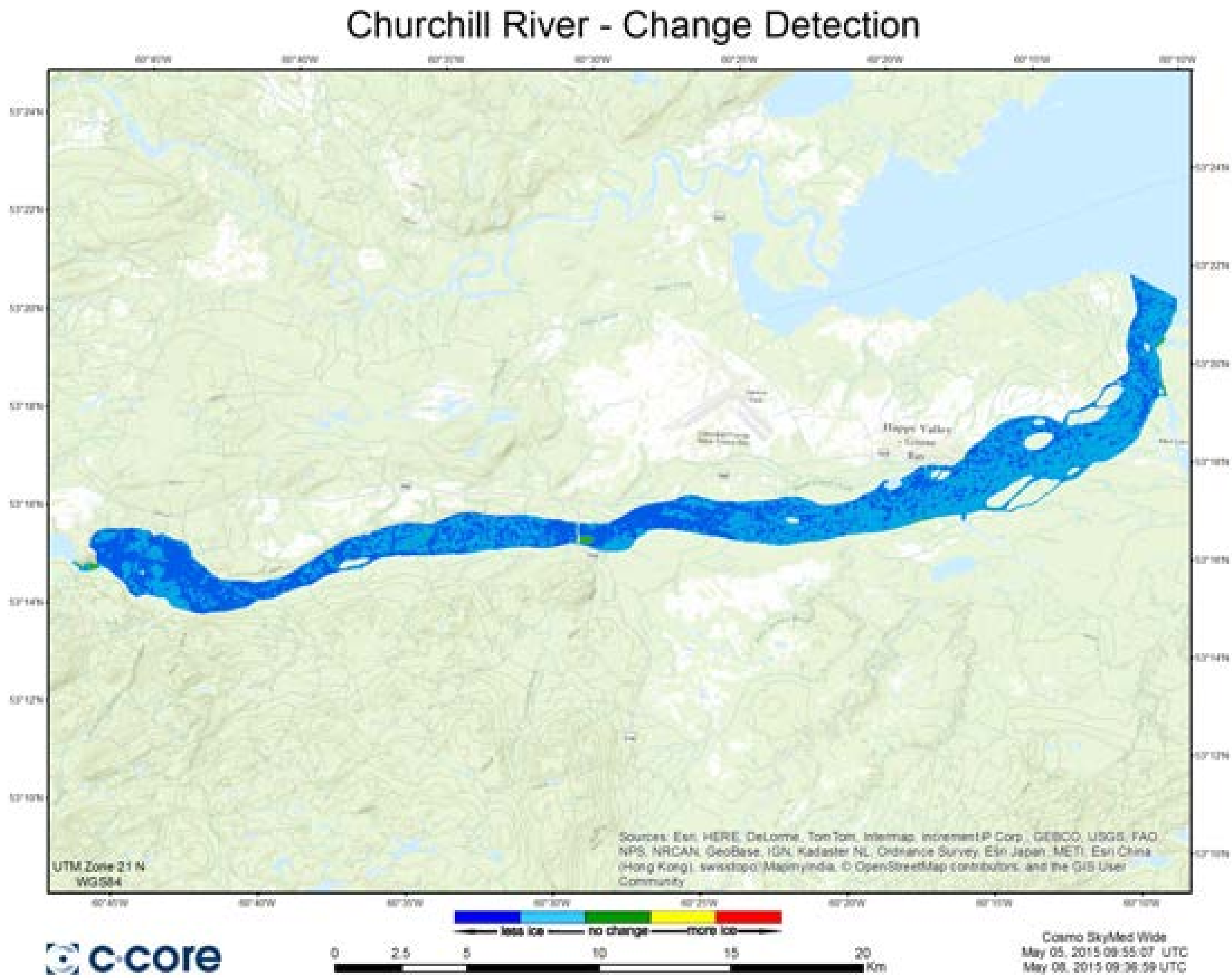


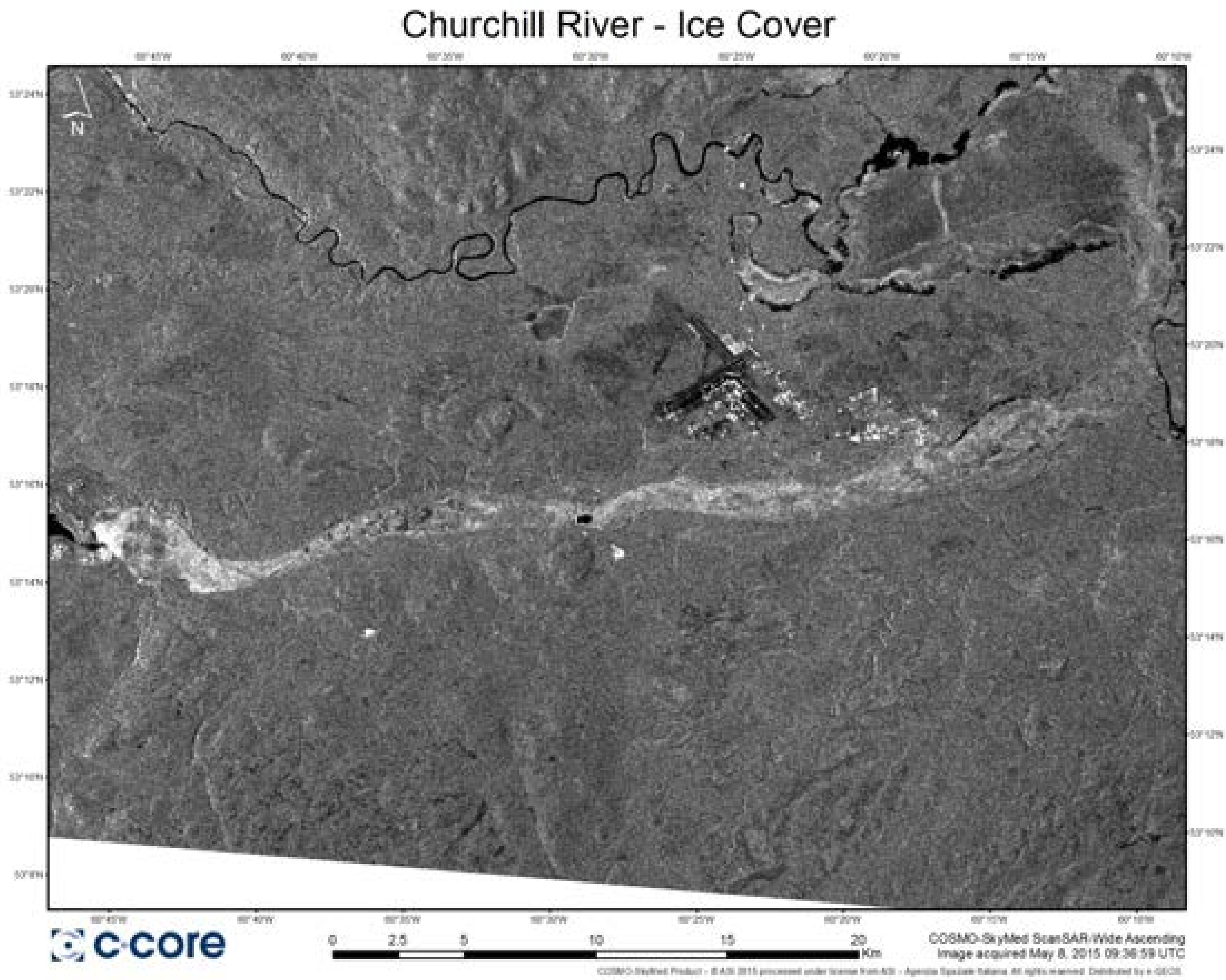

Churchill River - Change Detection
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
less ice
no change
more ice
0
2.5
5
10
15
20
Km
Cosmo SkyMed Wide
April 30, 2015 21:41:54 UTC
May 05, 2015 09:55:07 UTC

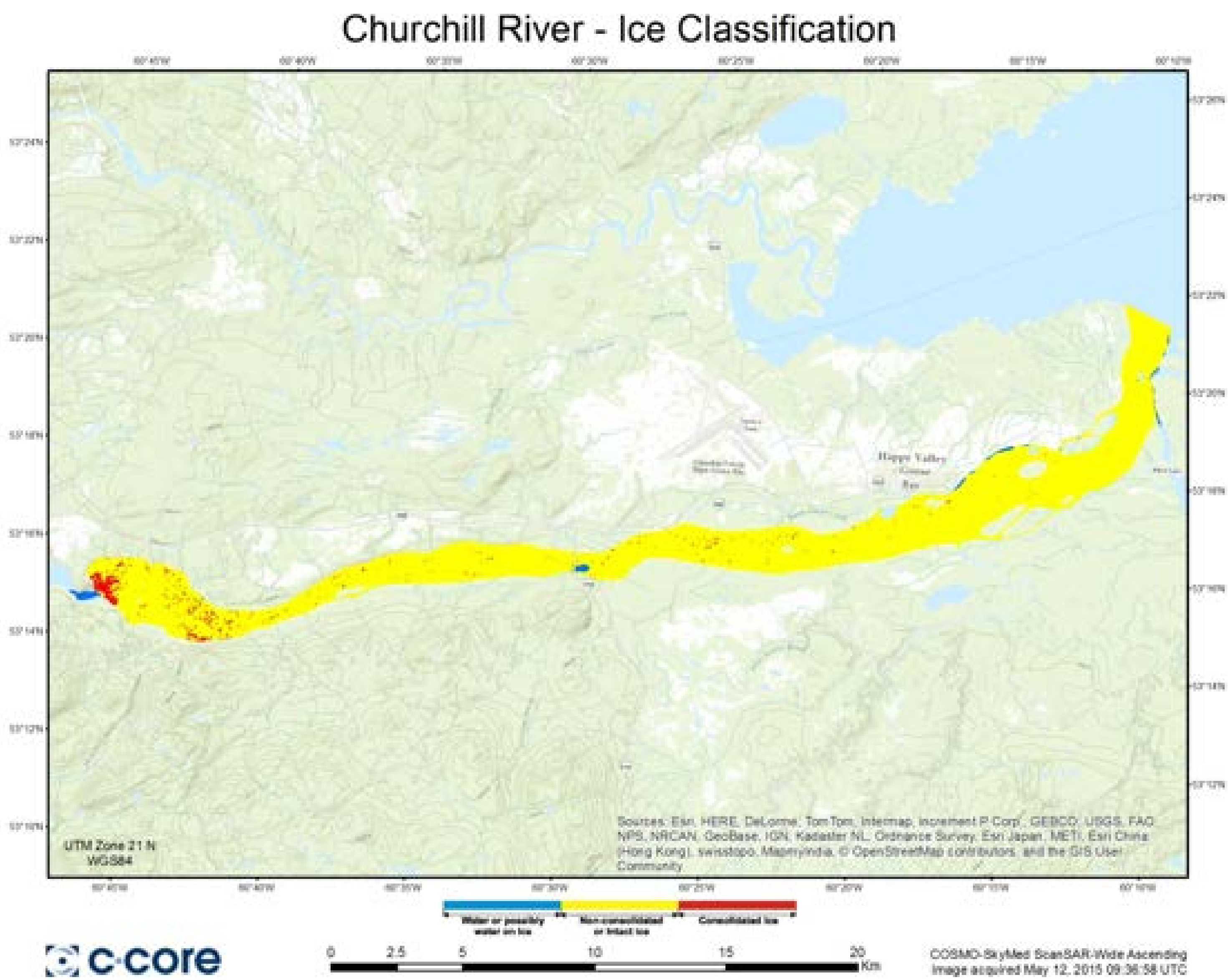
Churchill River - Ice Cover



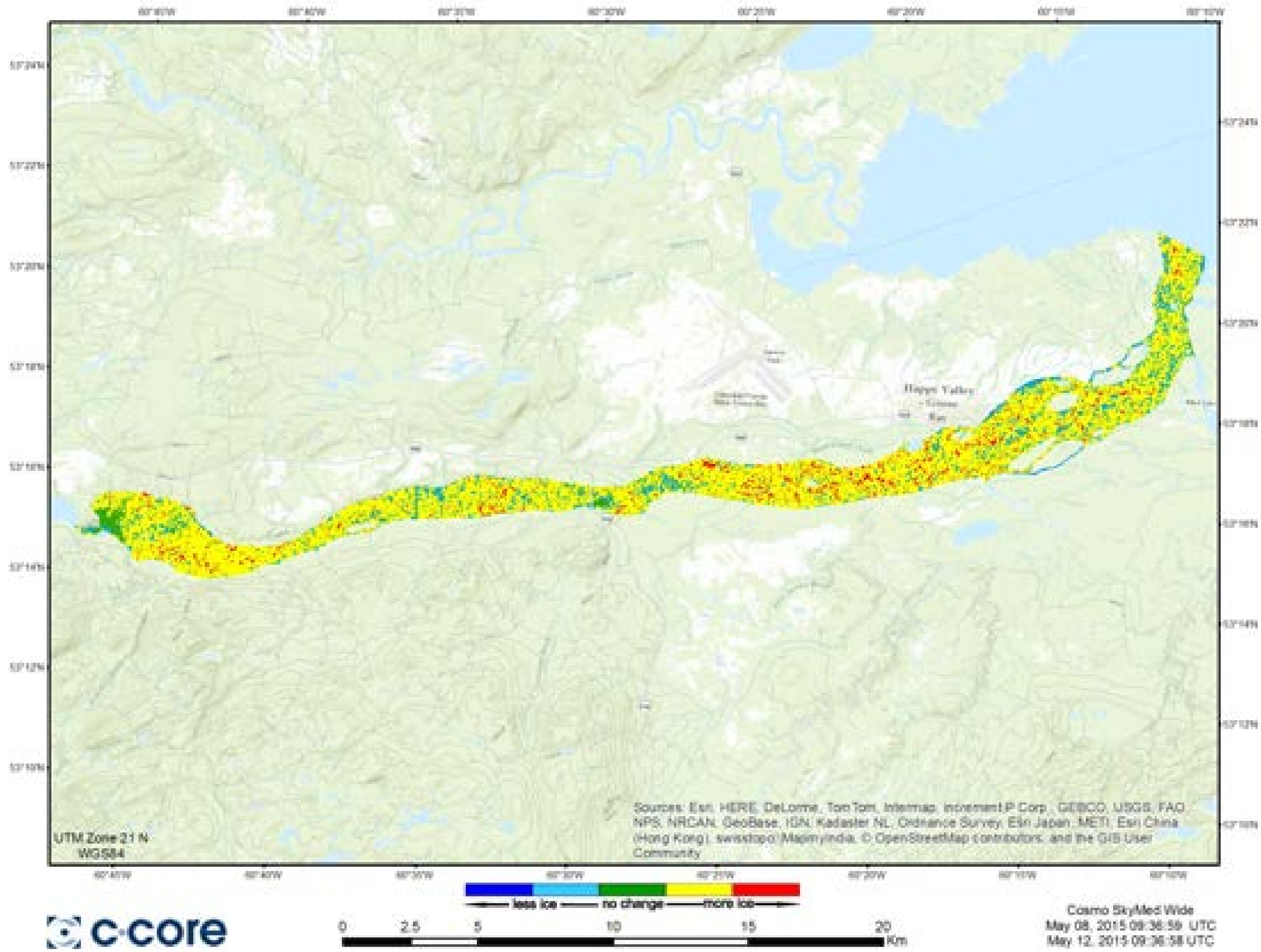

Churchill River - Ice Classification
Happy Valley
Goose
Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 8, 2015 09:36:59 UTC

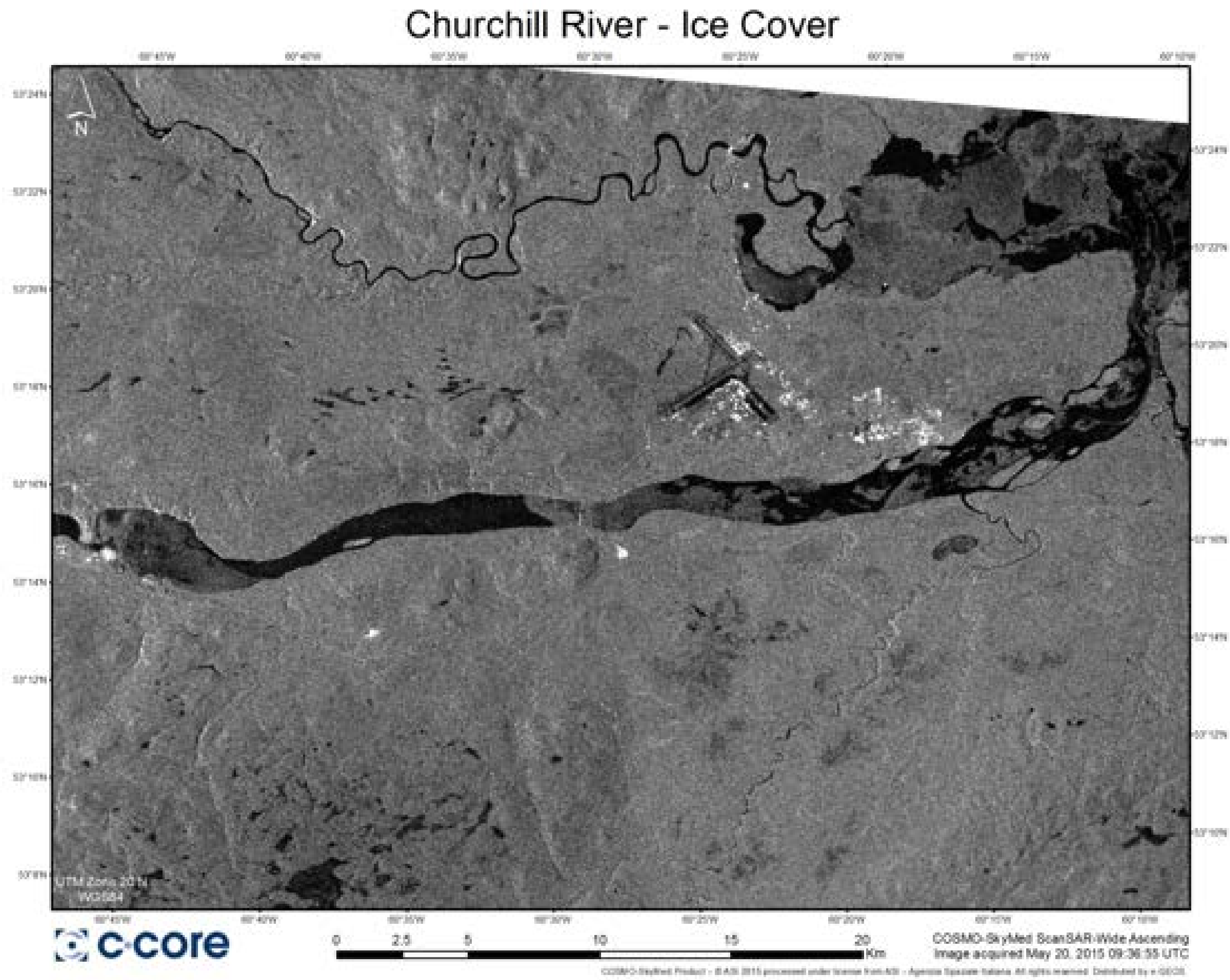

Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
Cosmo SkyMed Wide
May 05, 2015 09:55:07 UTC
May 08, 2015 09:36:59 UTC

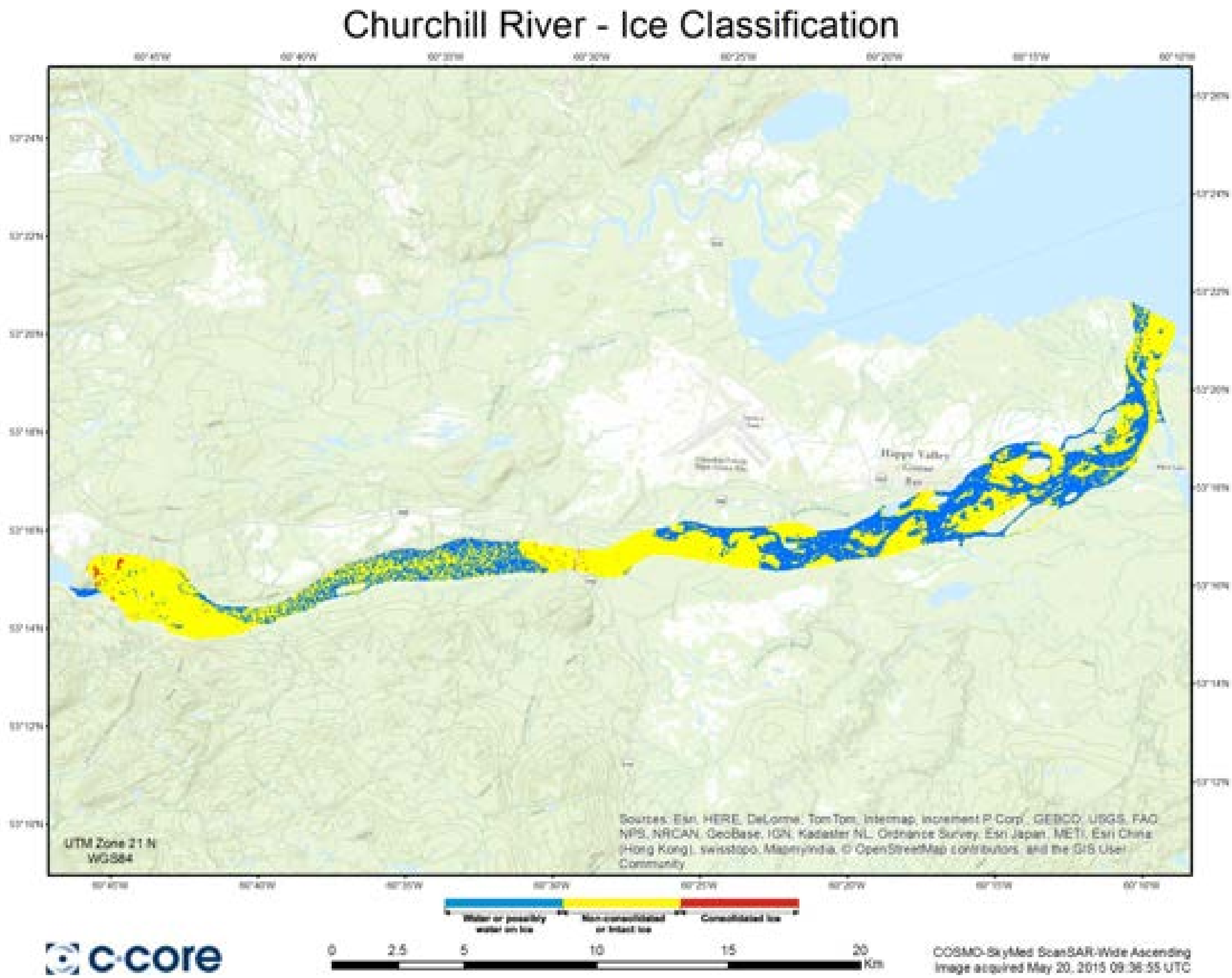

Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 8, 2015 09:36:59 UTC

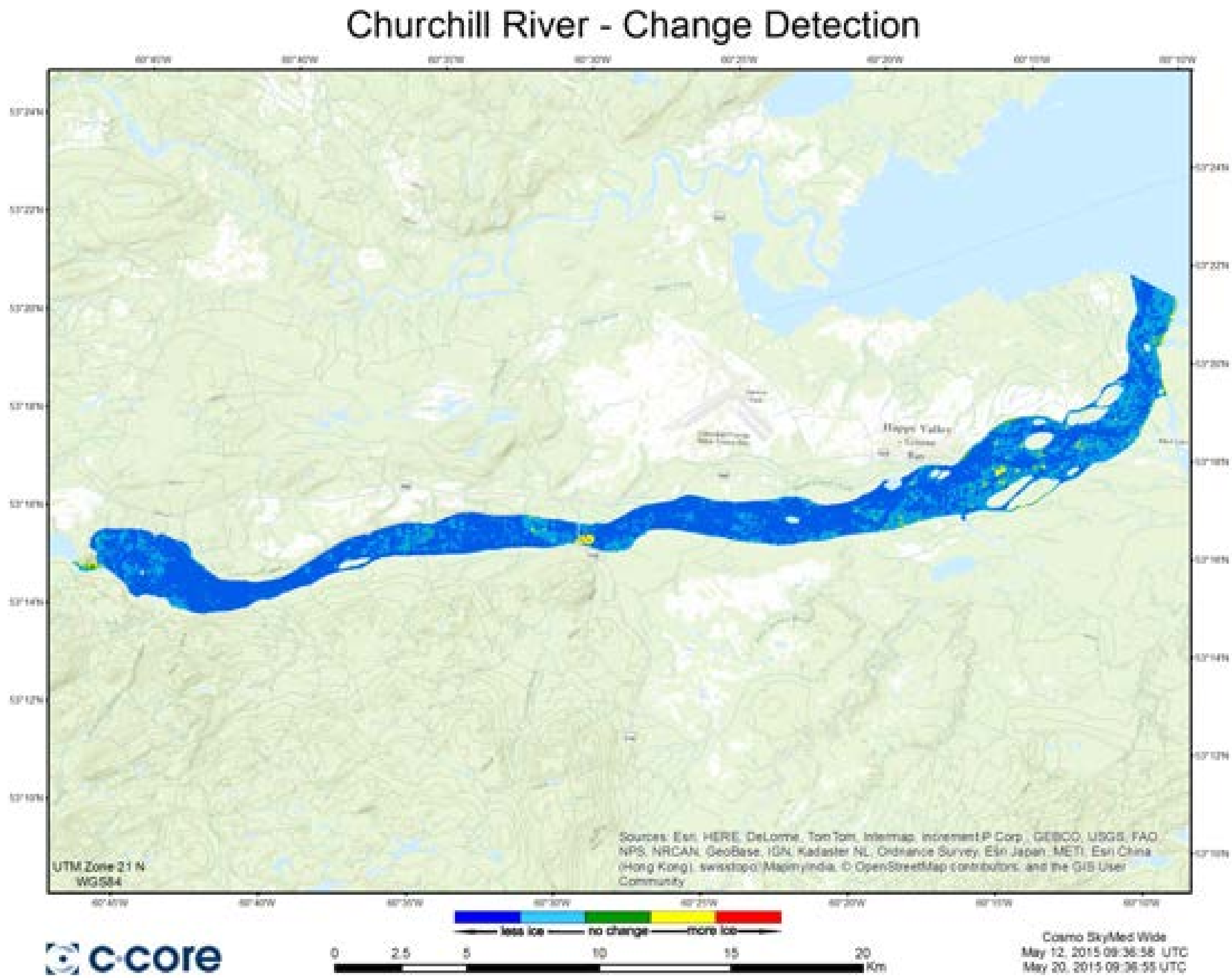

Churchill River - Ice Classification
Happy Valley
Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non consolidated or Intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 12, 2015 09:36:58 UTC

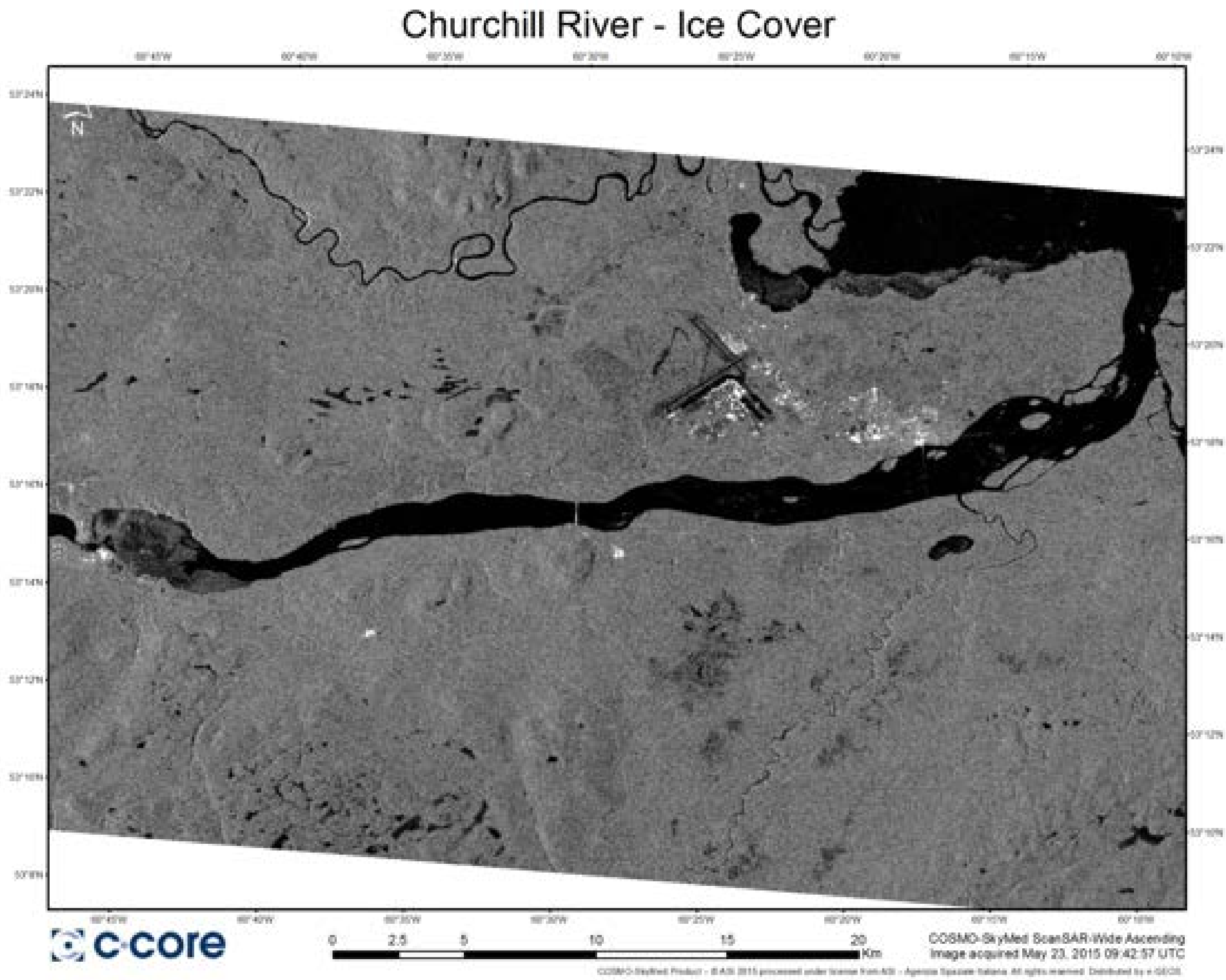
Churchill River - Change Detection



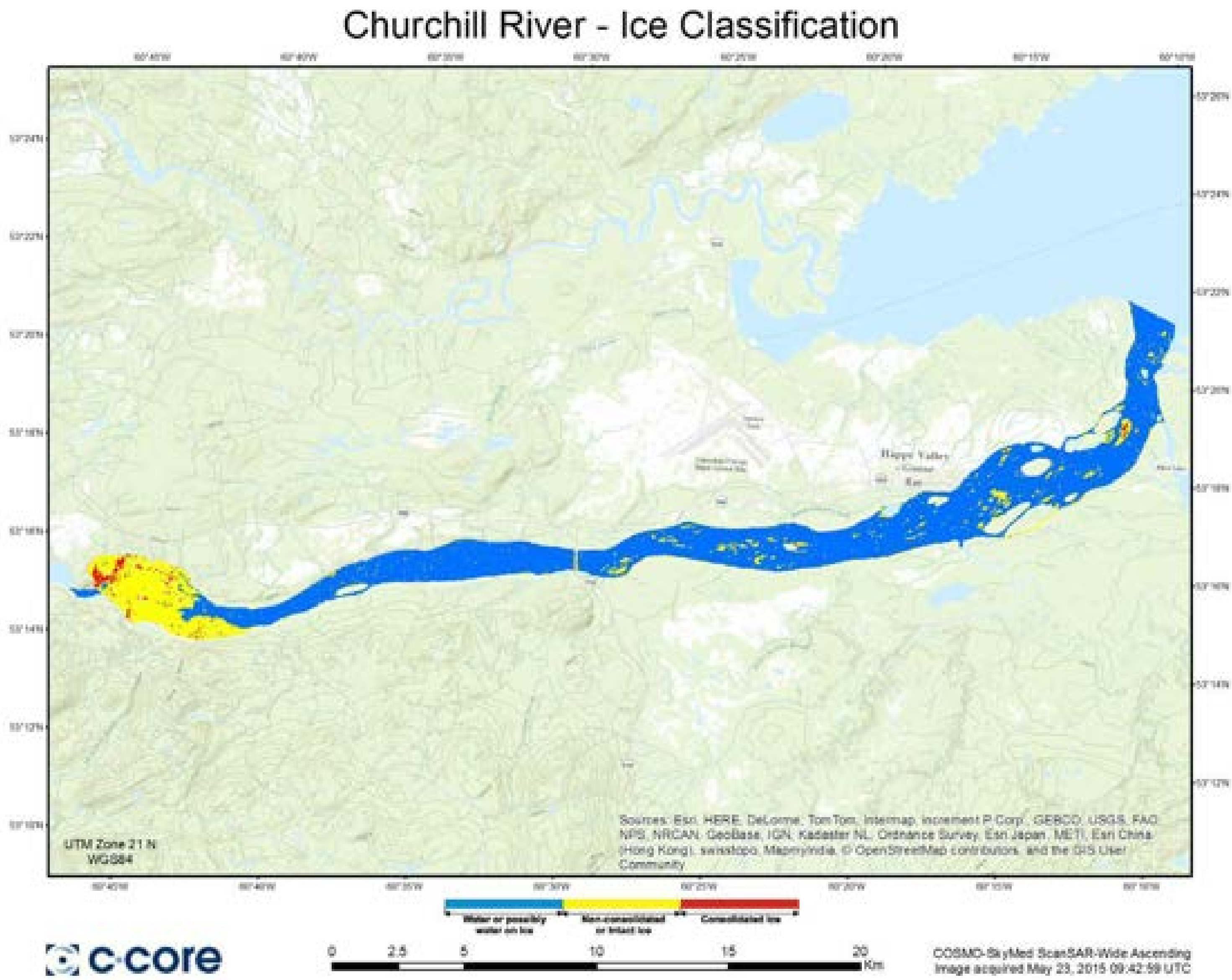

Churchill River - Ice Cover
N
UTM Zone 20 N
WGS84
c·core
0 2.5 5 10 15 20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 20, 2015 09:36:55 UTC

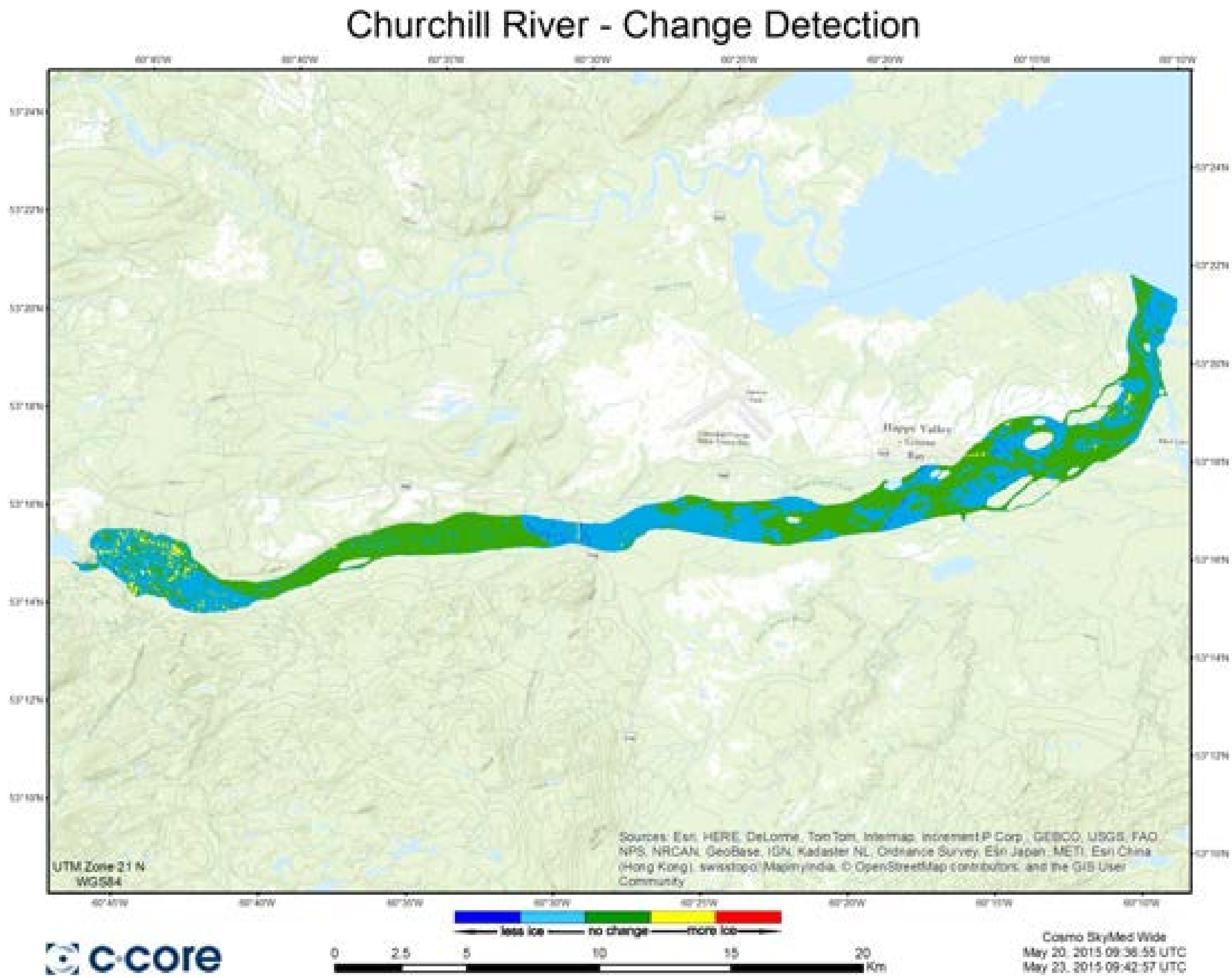

Churchill River - Ice Classification
Happy Valley
Goose
Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0
2.5
5
10
15
20
Km
c·core
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 20, 2015 09:36:55 UTC


Churchill River - Change Detection
Happy Valley - Goose Bay
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
less ice
no change
more ice
0
2.5
5
10
15
20
Km
Cosmo SkyMed Wide
May 12, 2015 09:36:58 UTC
May 20, 2015 09:36:55 UTC



Churchill River - Ice Cover
N
0
2.5
5
10
15
20
Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 23, 2015 09:42:57 UTC

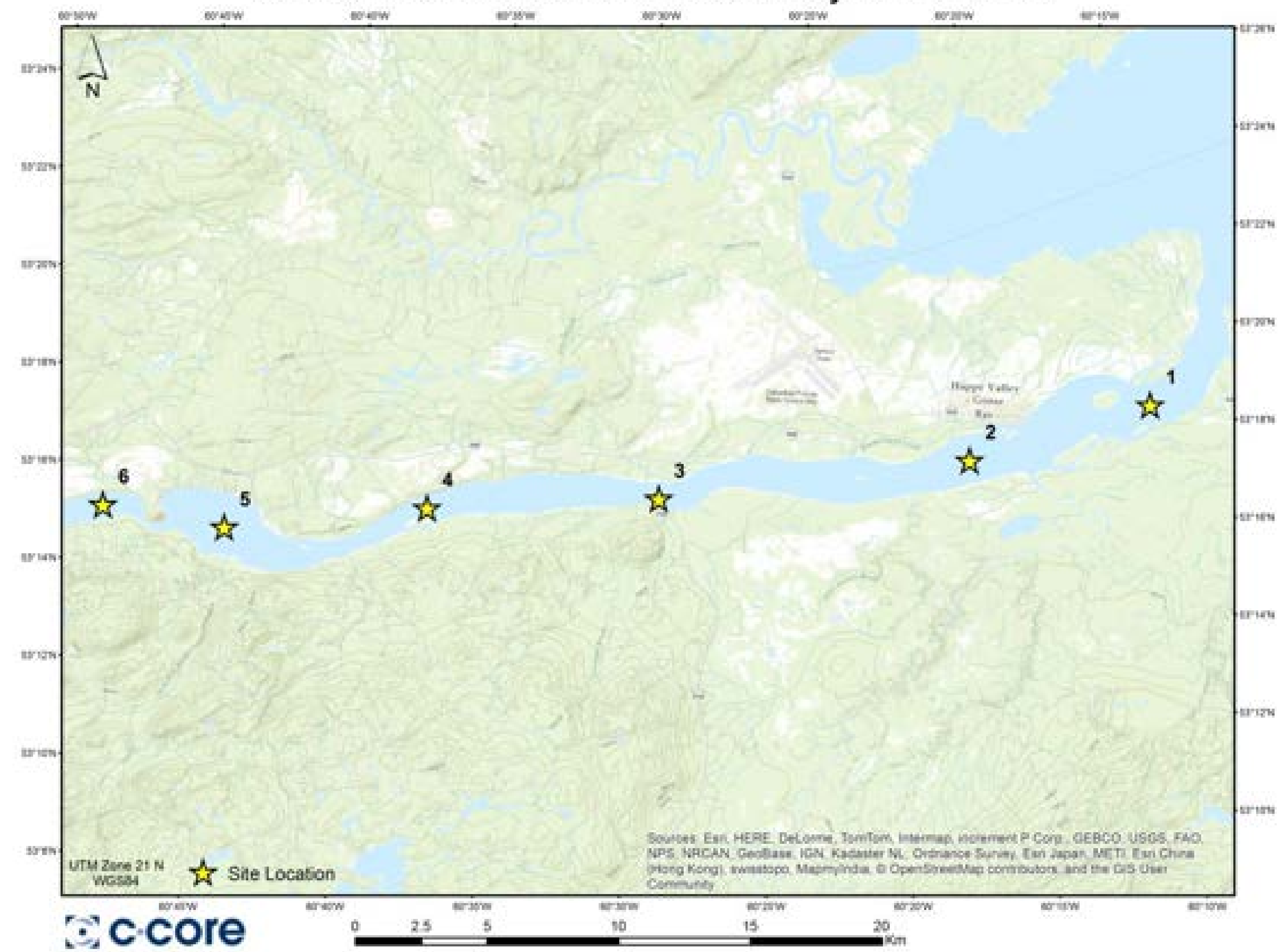

Churchill River - Ice Classification
UTM Zone 21 N
WGS84
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Water or possibly water on ice
Non-consolidated or intact ice
Consolidated ice
0 2.5 5 10 15 20 Km
COSMO-SkyMed ScanSAR-Wide Ascending
Image acquired May 23, 2015 09:42:59 UTC

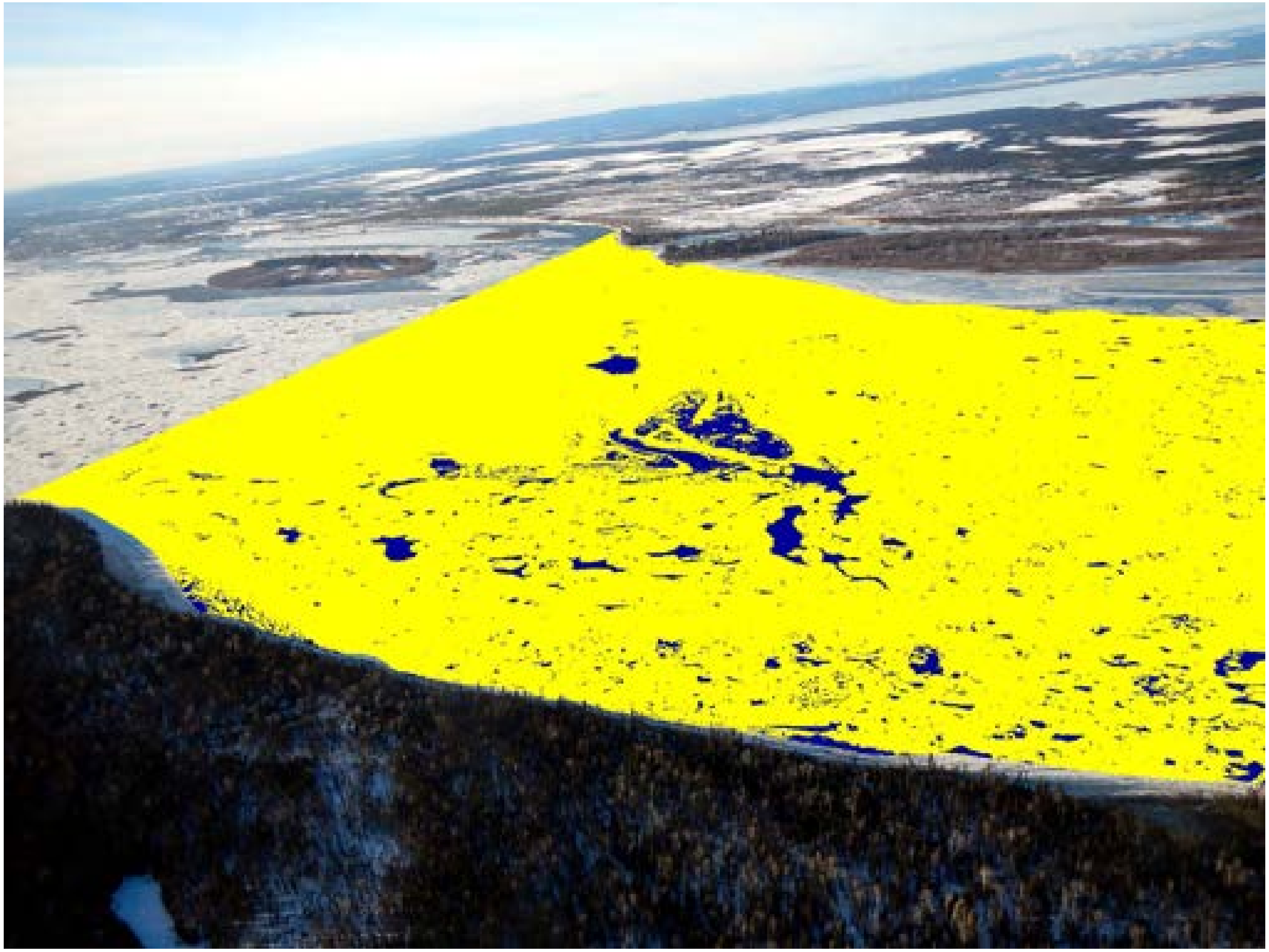

Churchill River - Change Detection
Happy Valley - Goose Bay
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
UTM Zone 21 N
WGS84
less ice
no change
more ice
0 2.5 5 10 15 20
Km
c·core
Cosmo SkyMed Wide
May 20, 2015 09:36:55 UTC
May 23, 2015 09:42:57 UTC

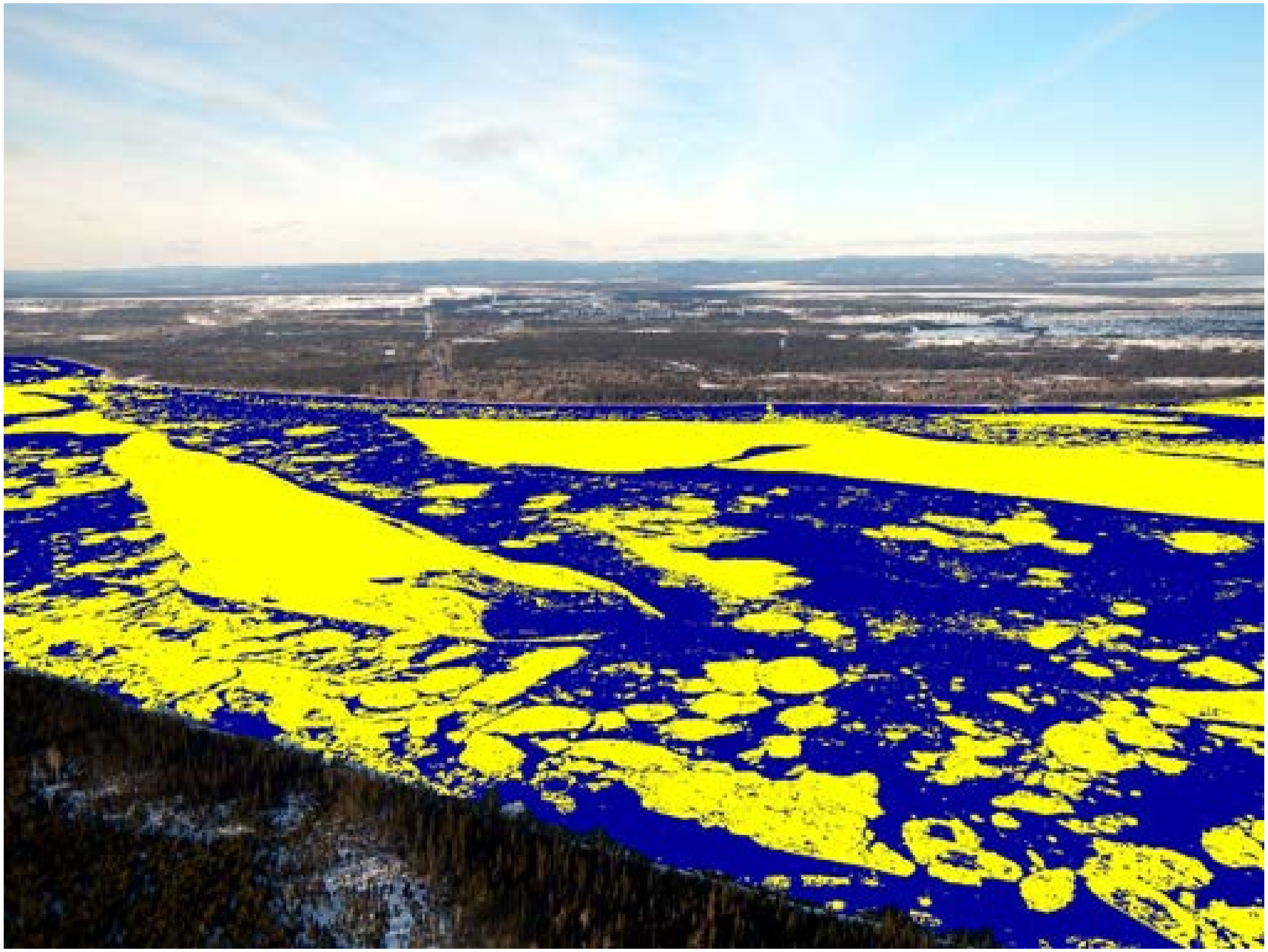
APPENDIX E

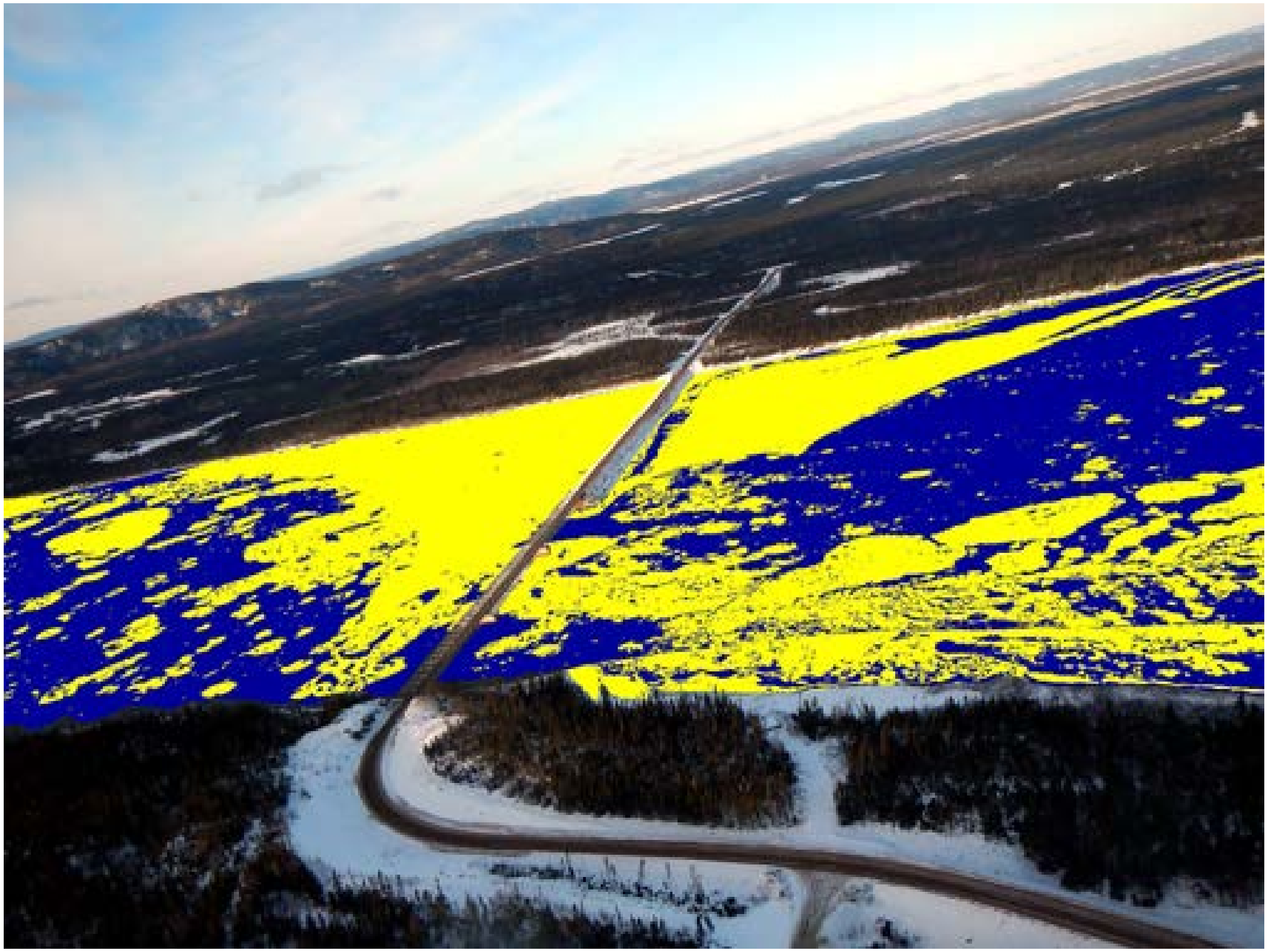
Ice Floe Analyses During Freeze-up

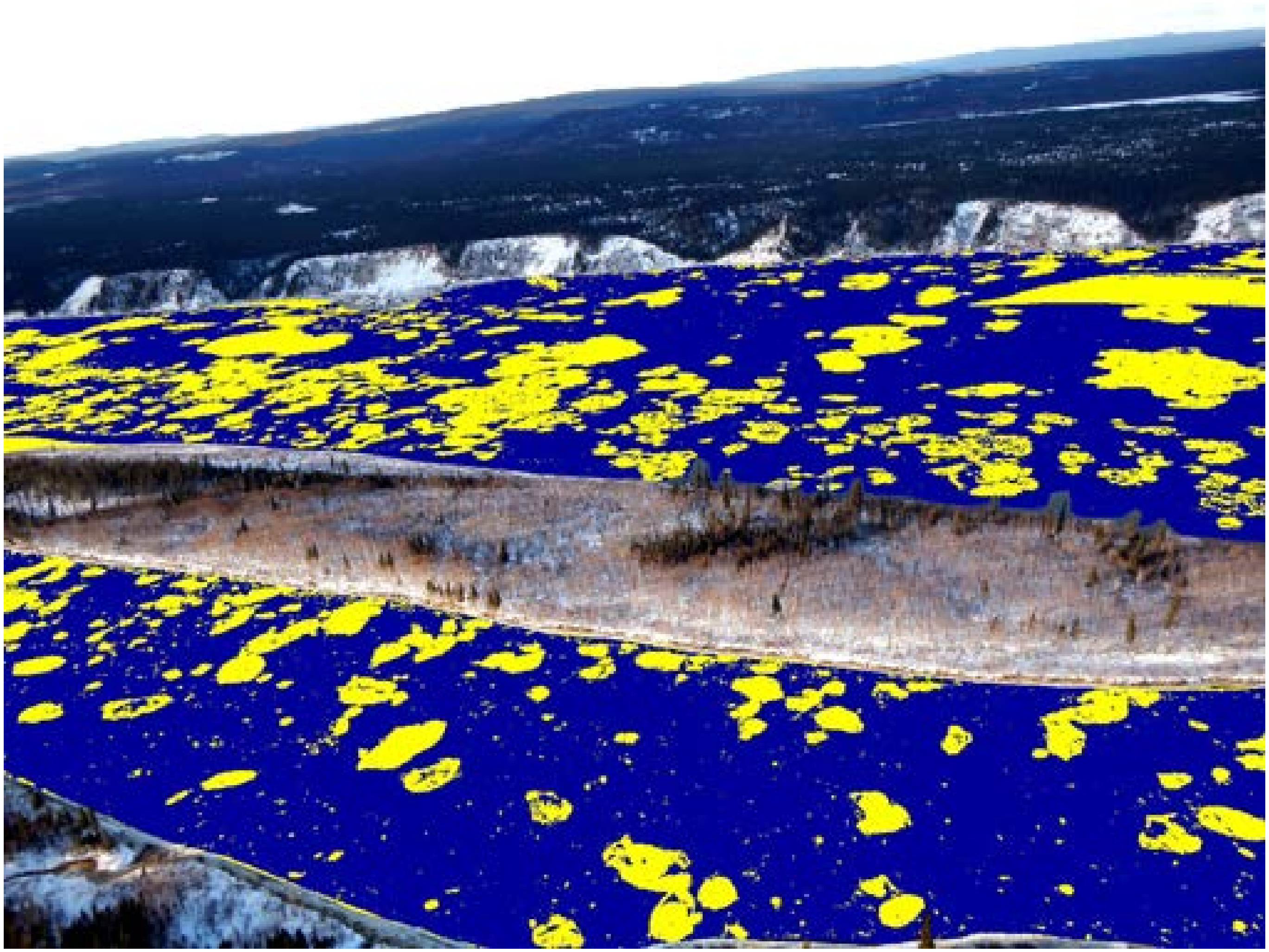
Churchill River - Aerial Photo Analysis 2014-15

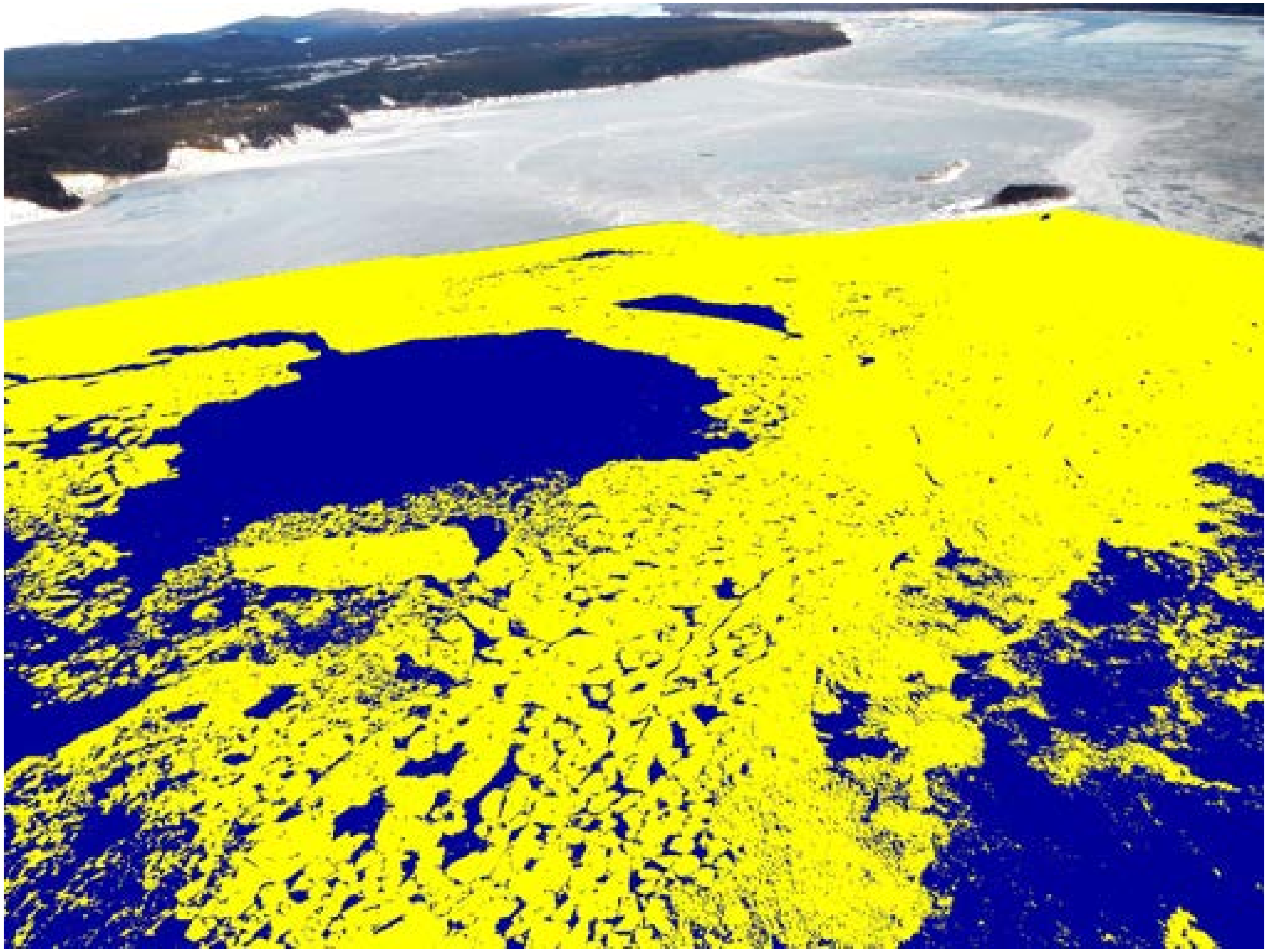


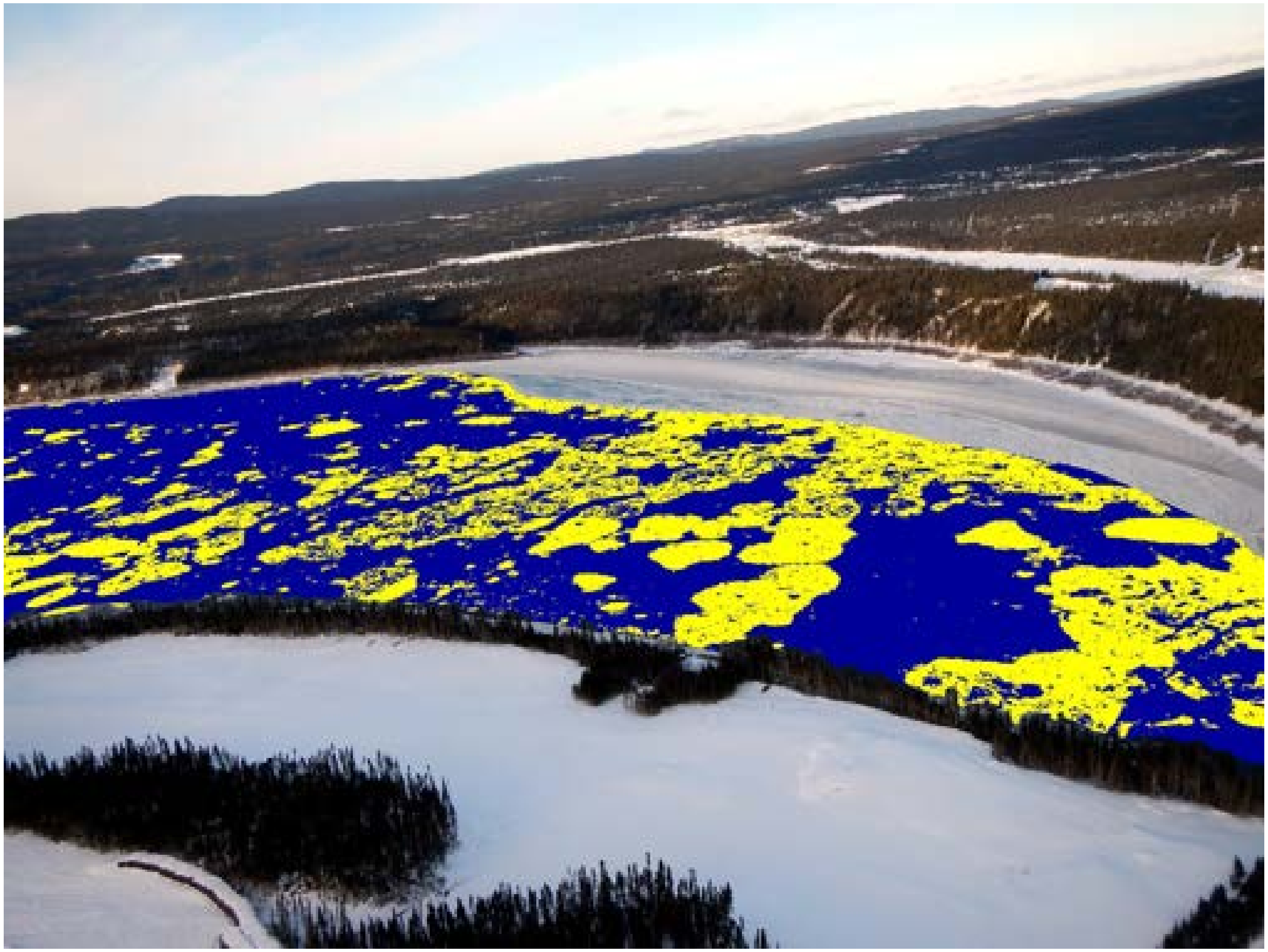


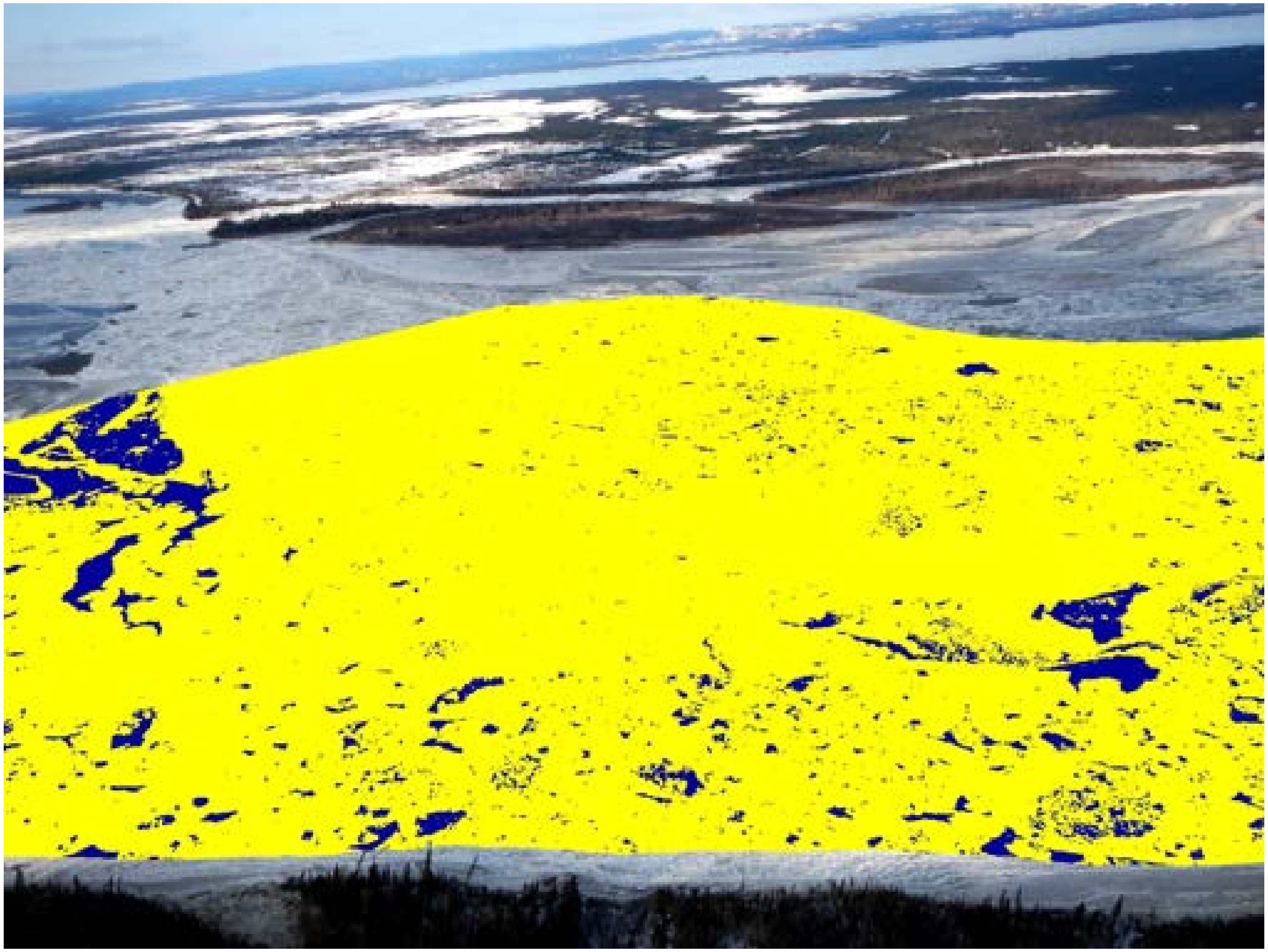


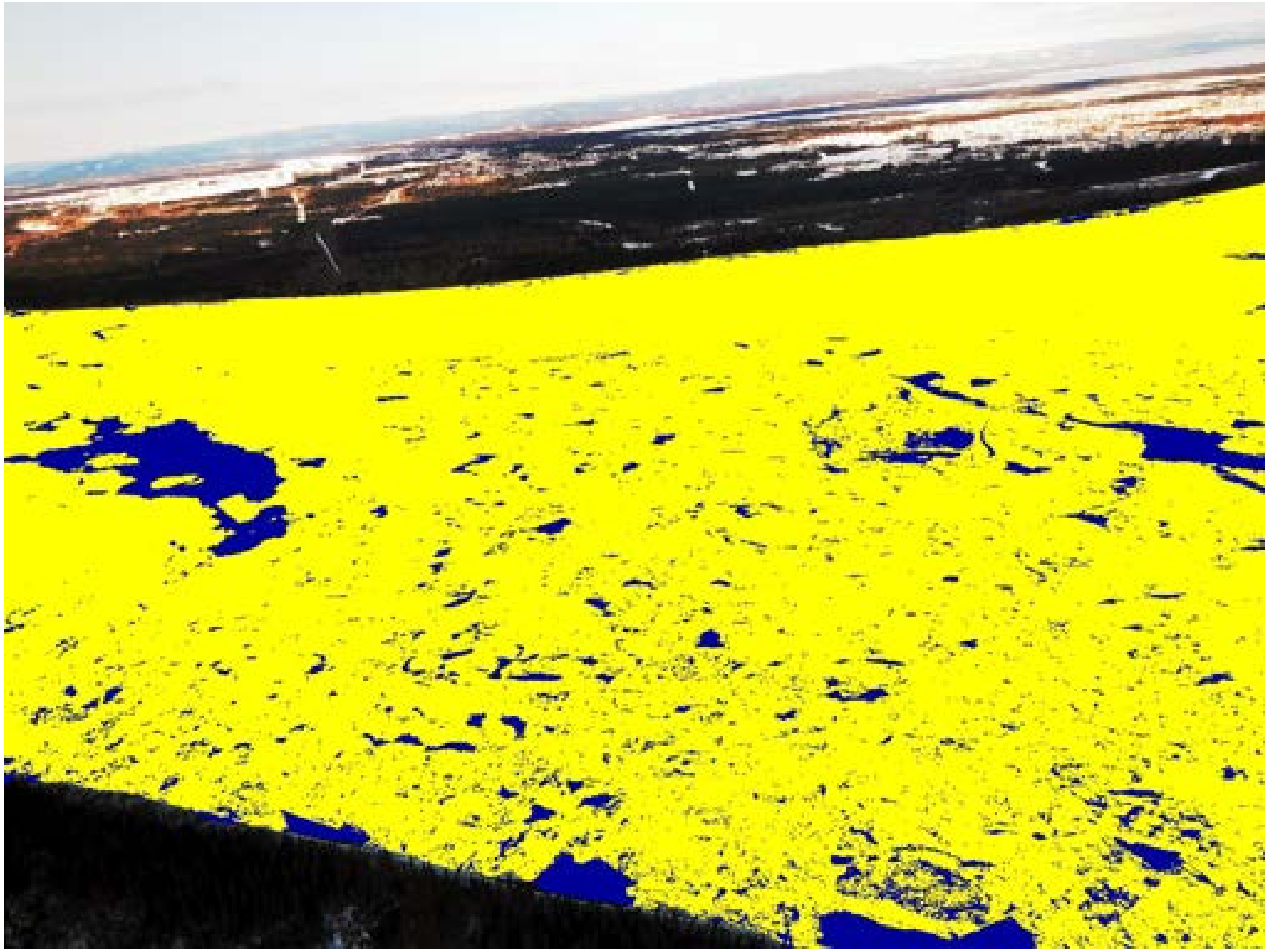


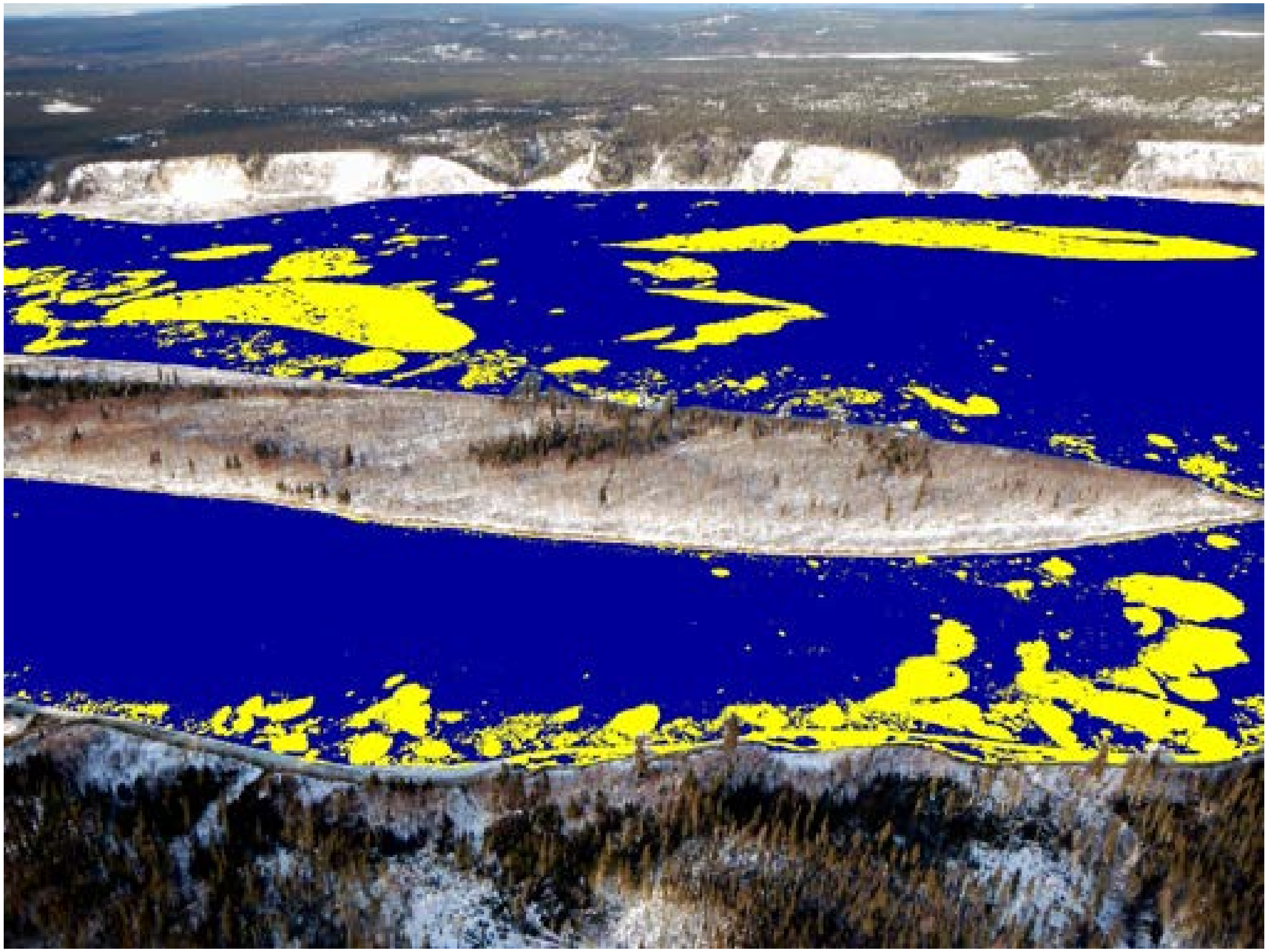


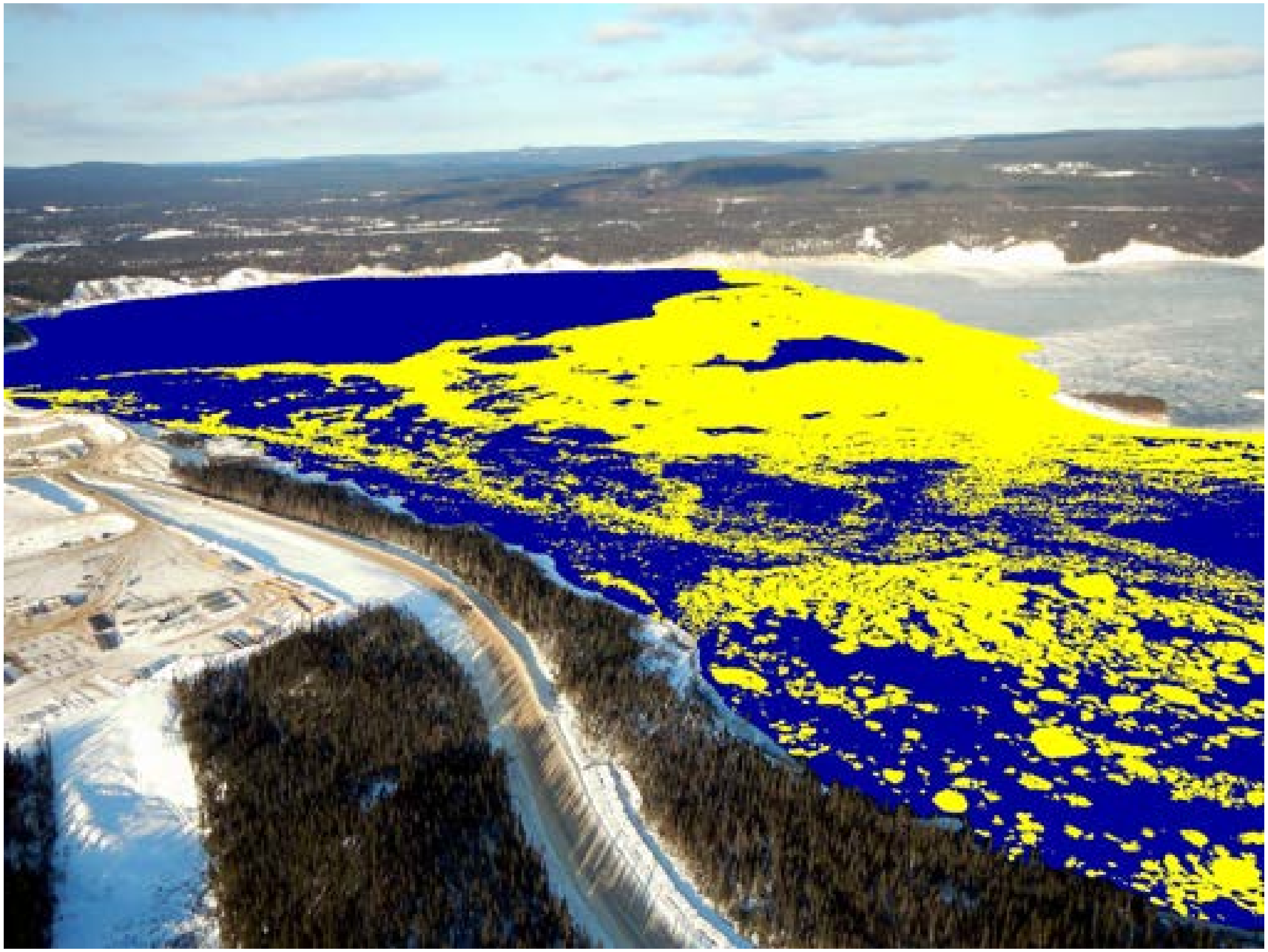


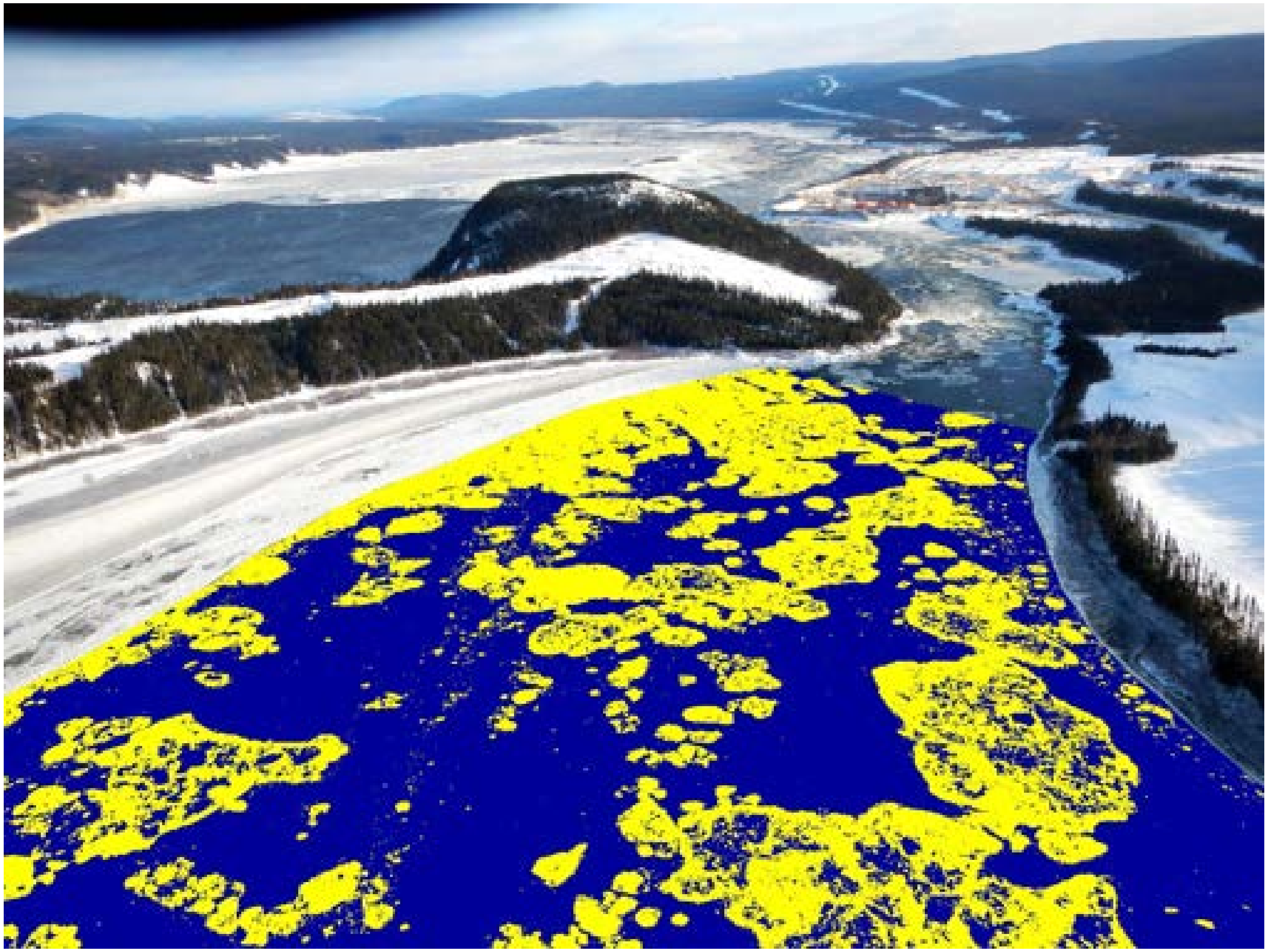


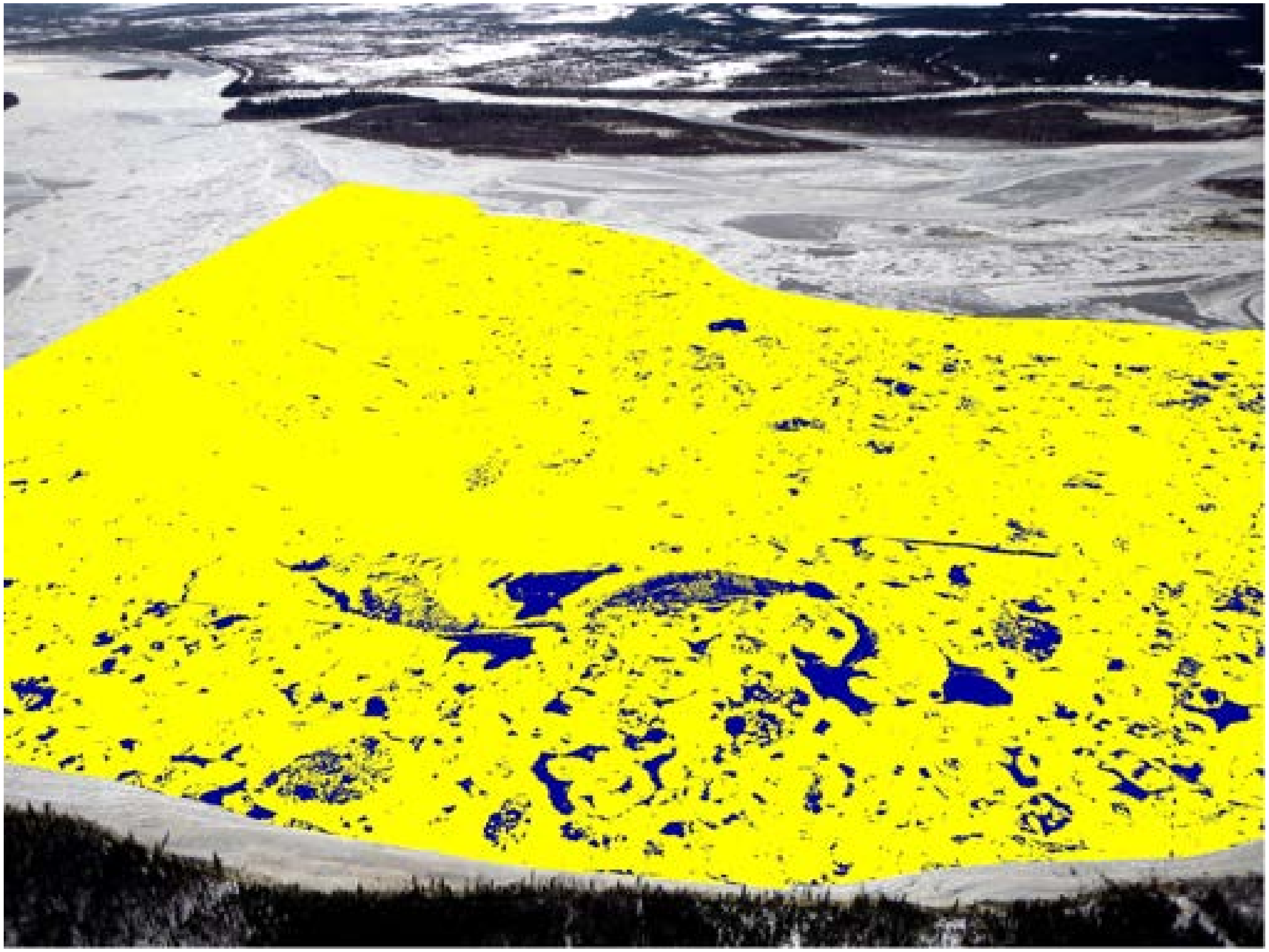


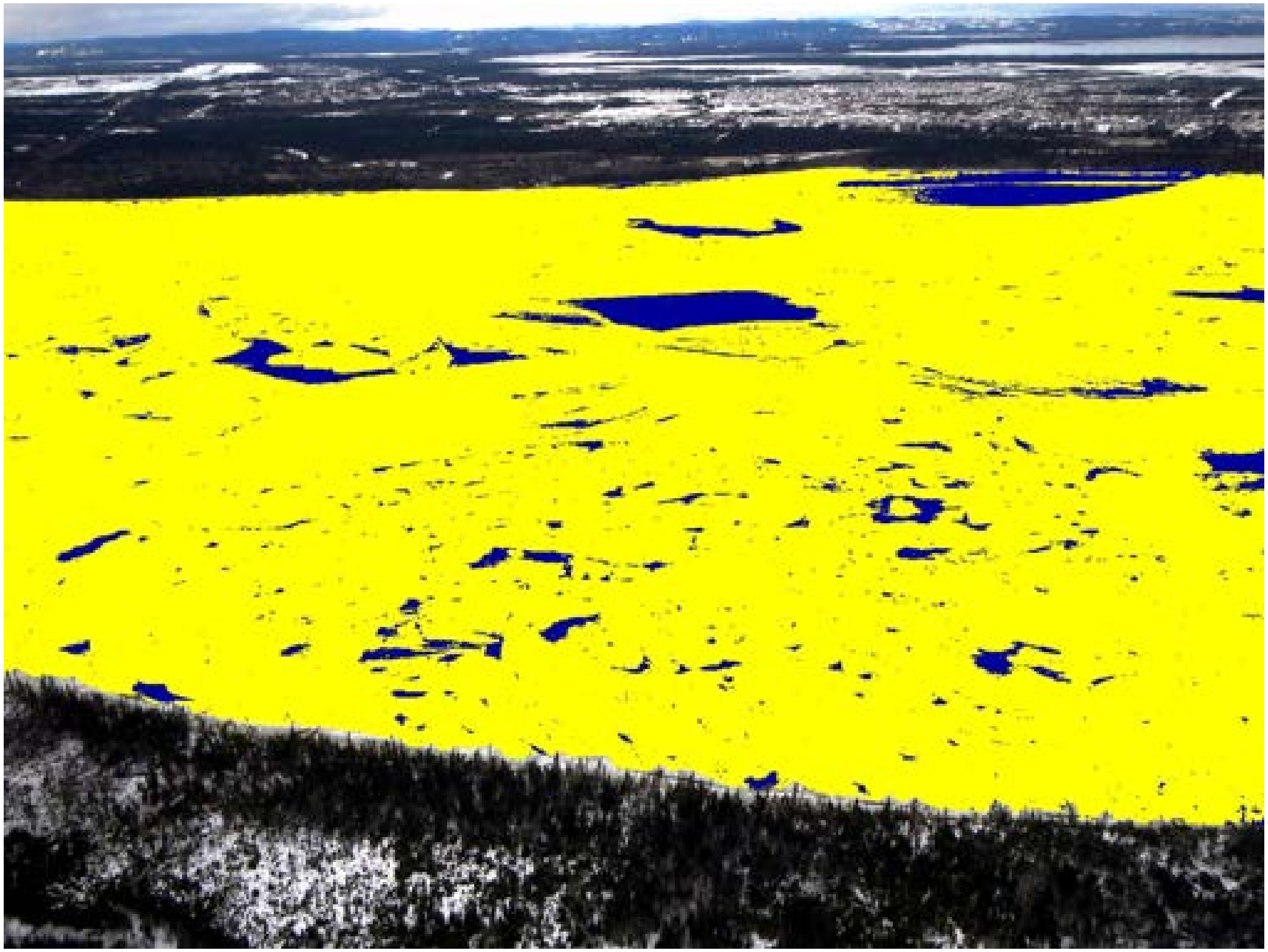


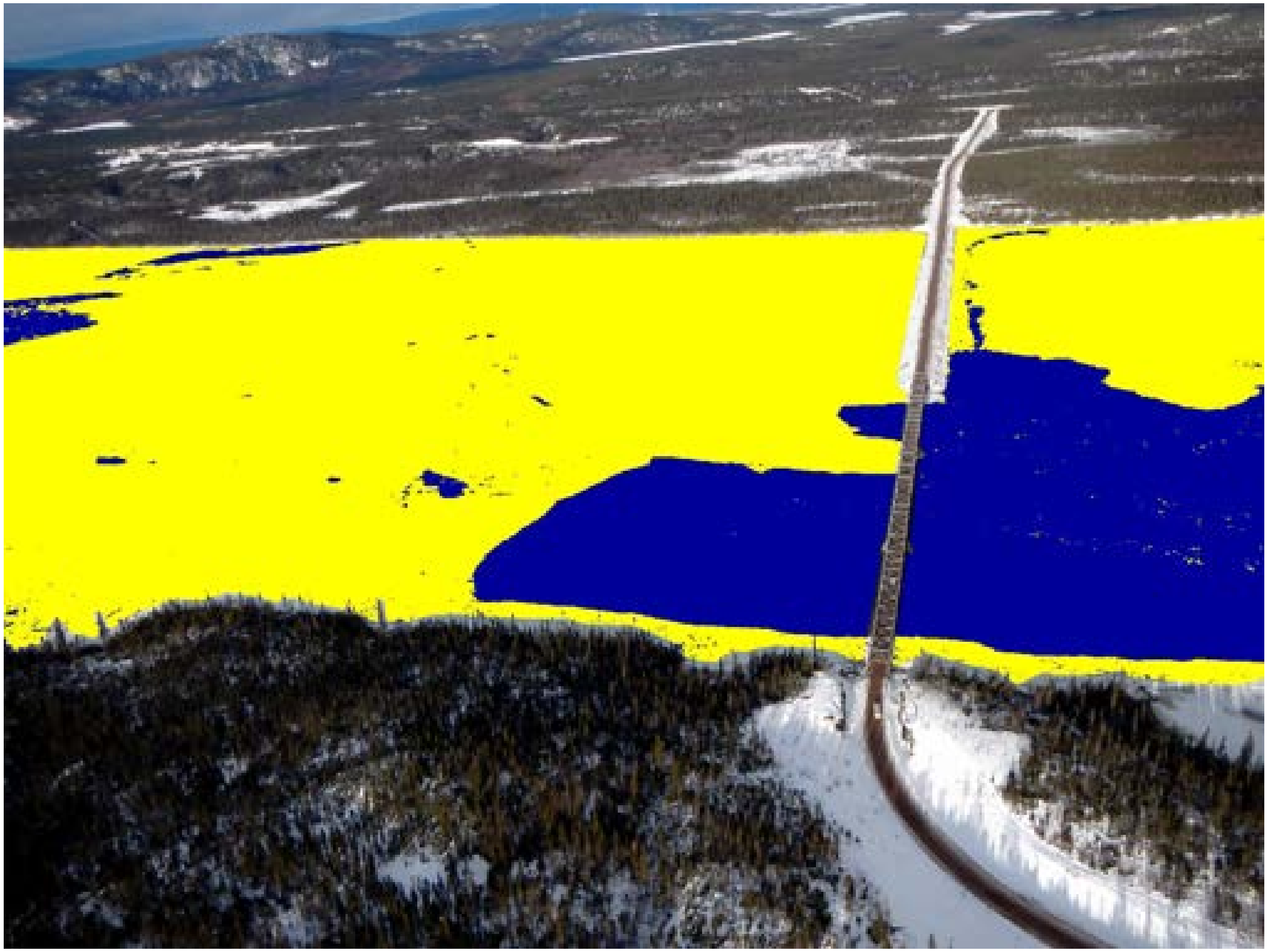


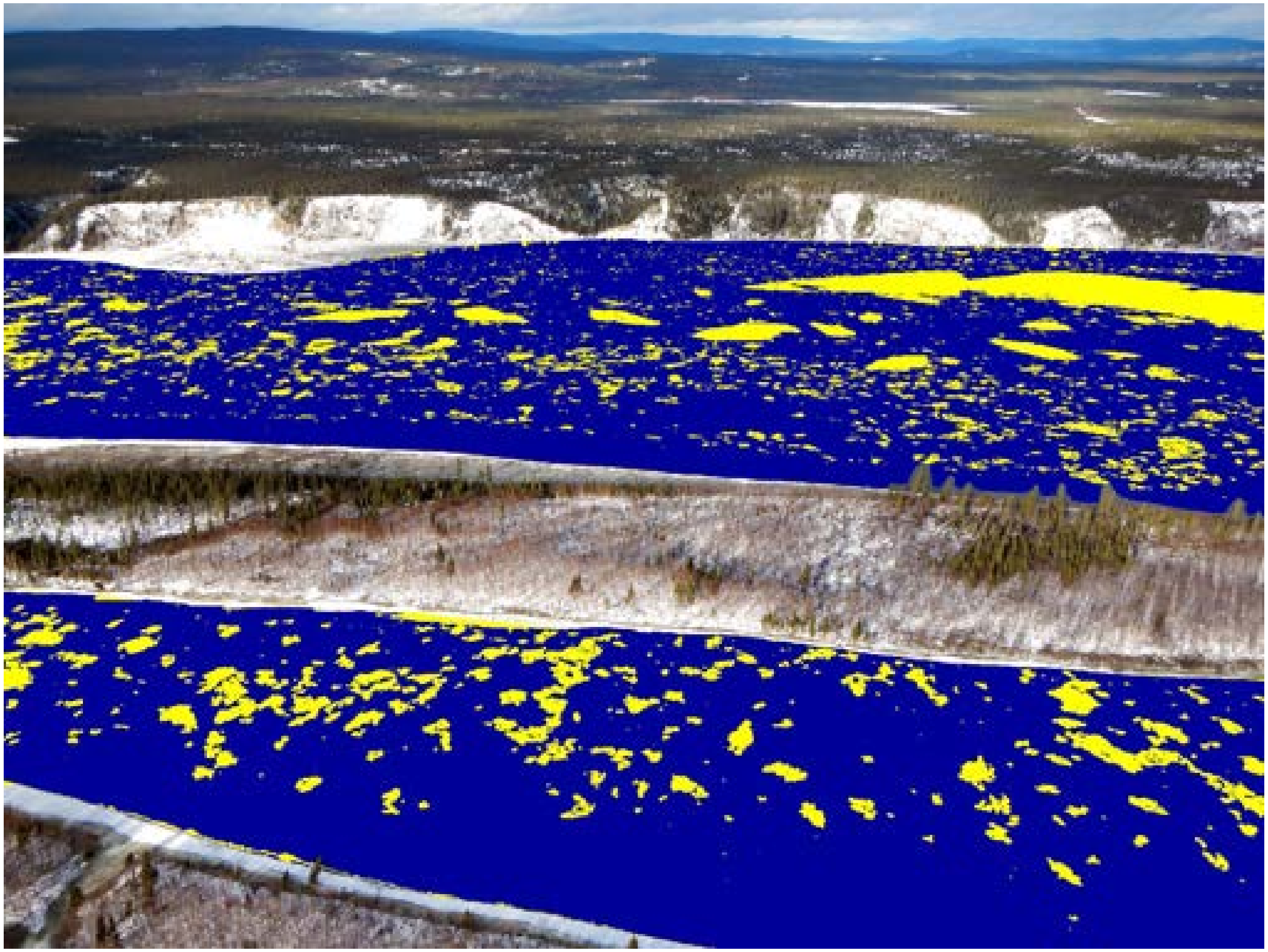


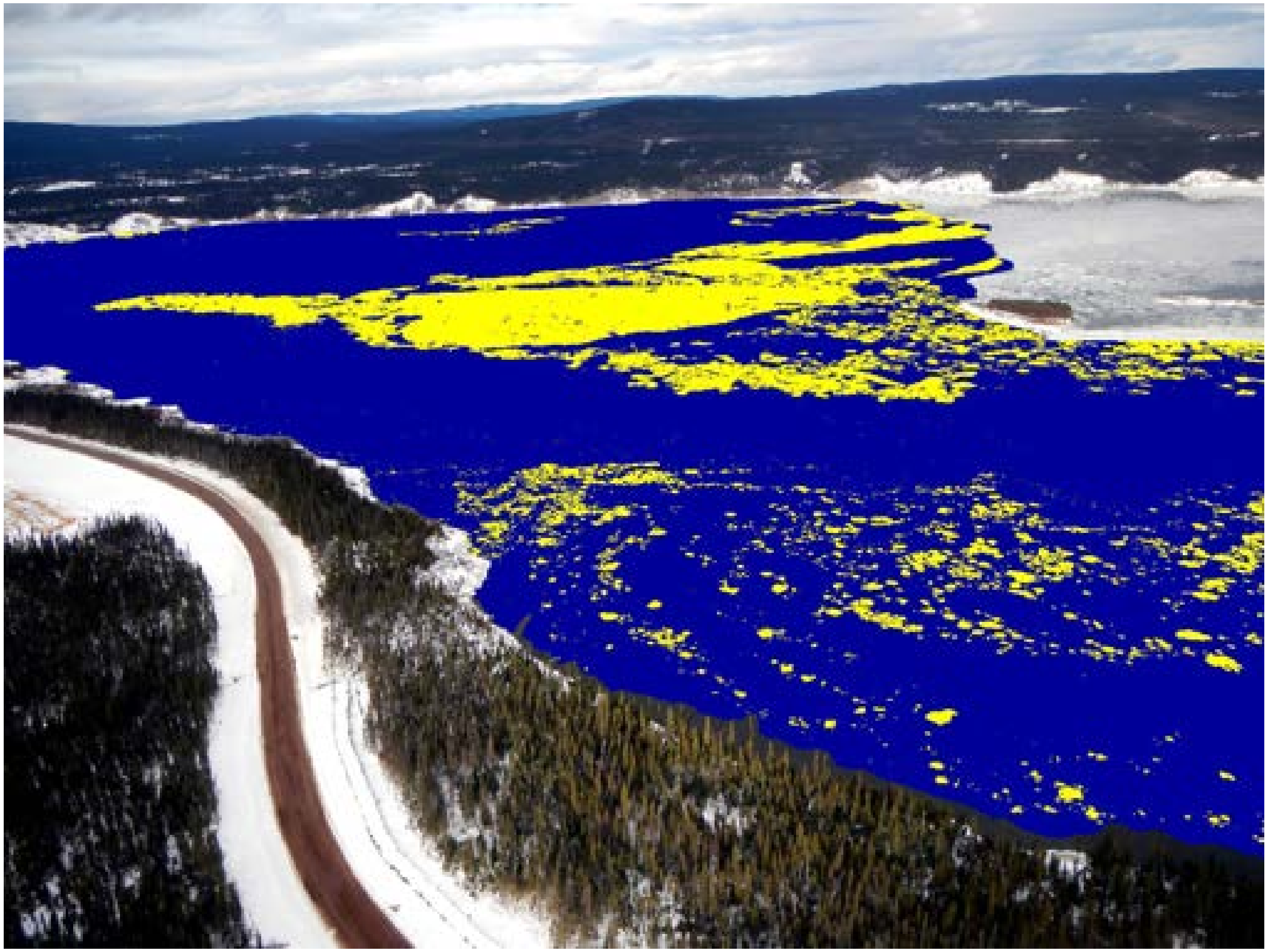








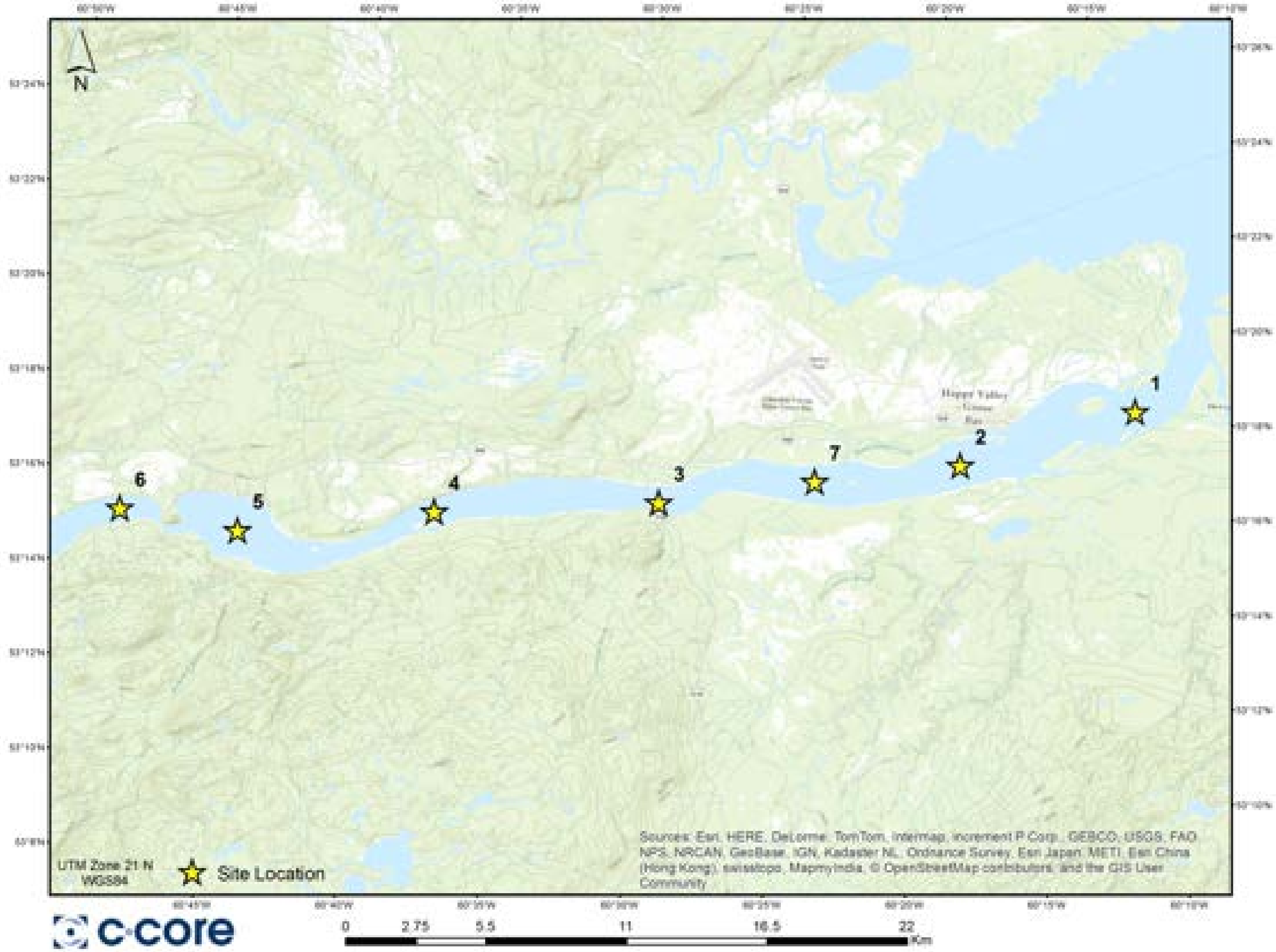


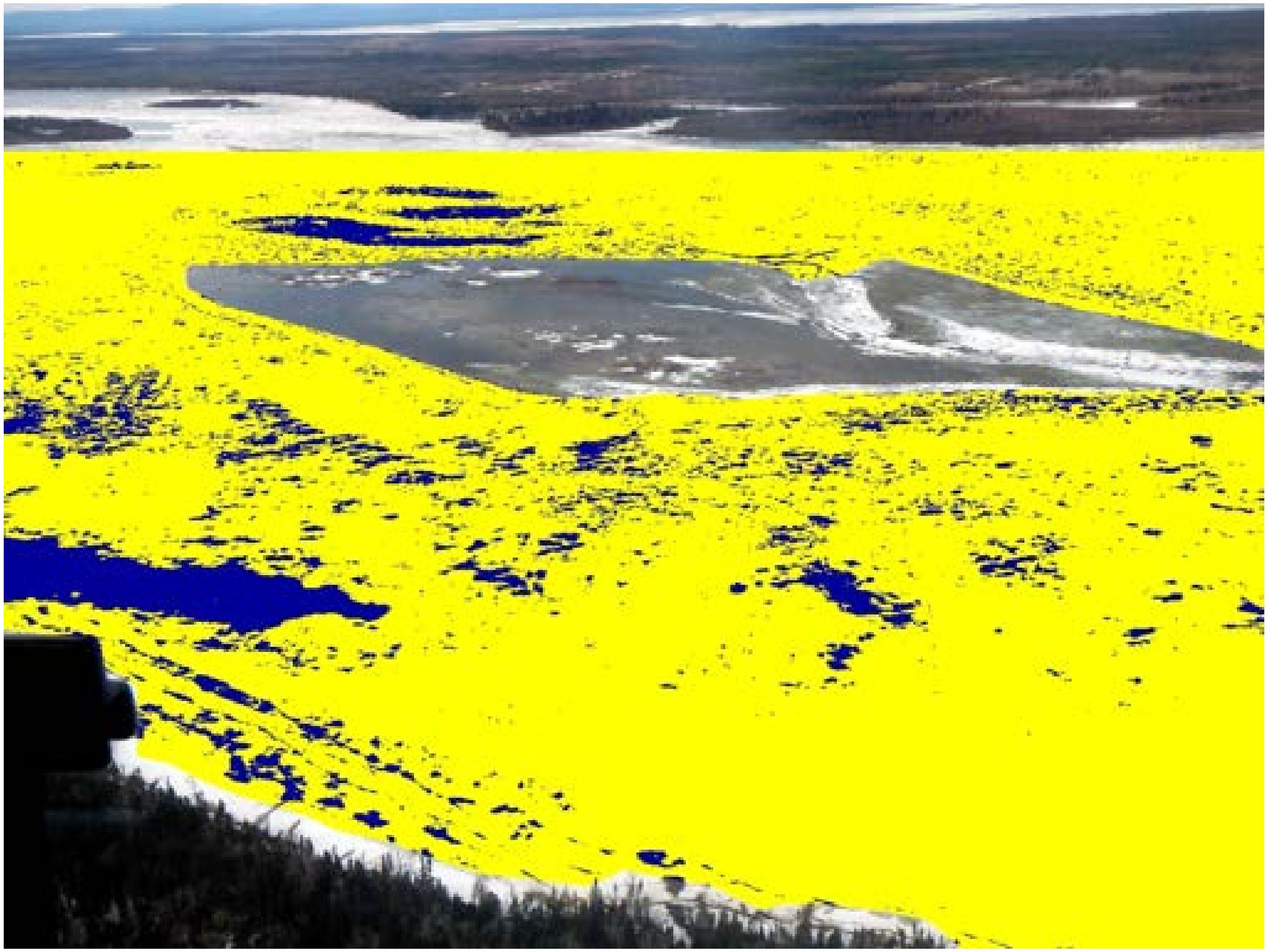


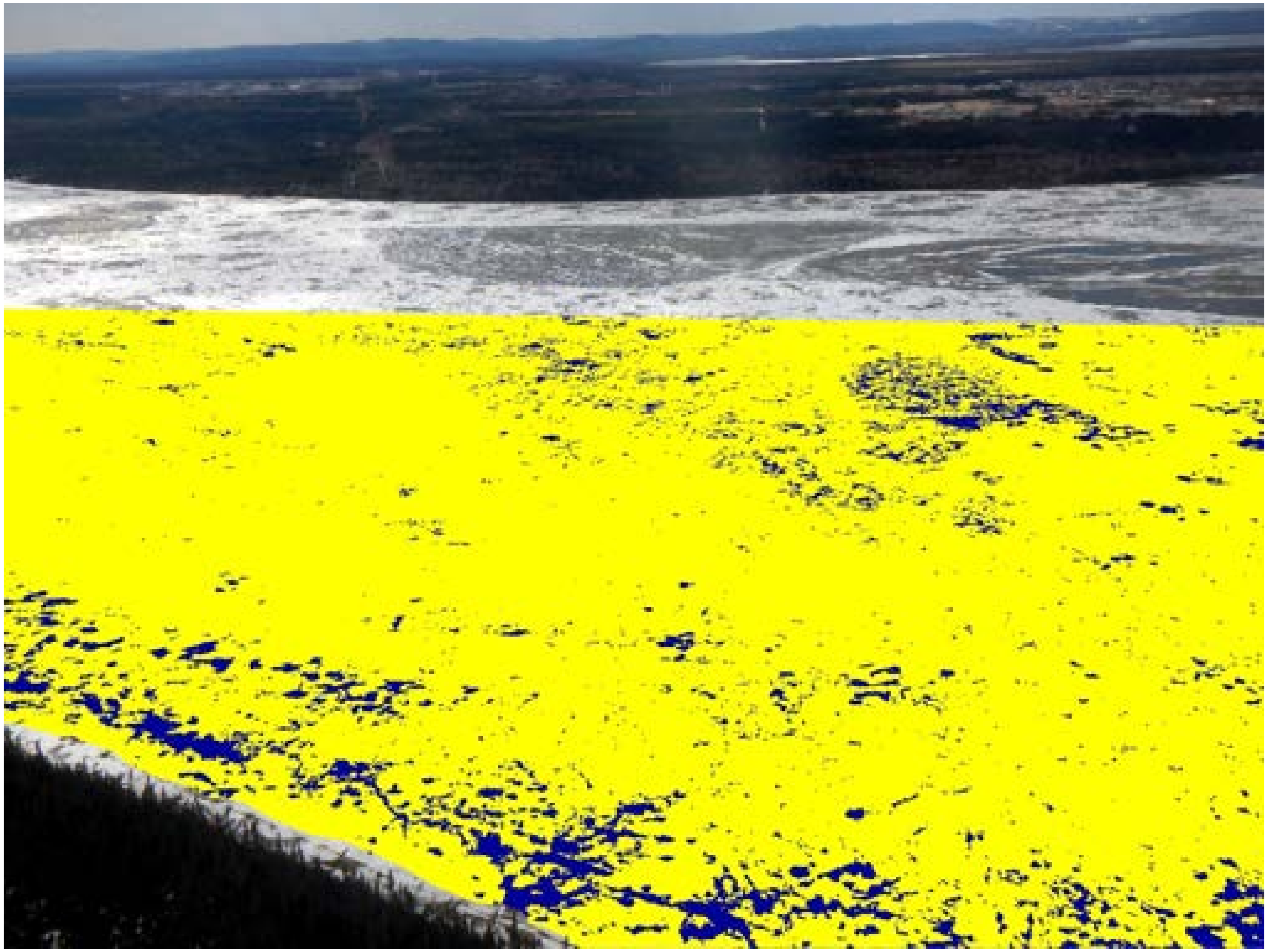
APPENDIX F

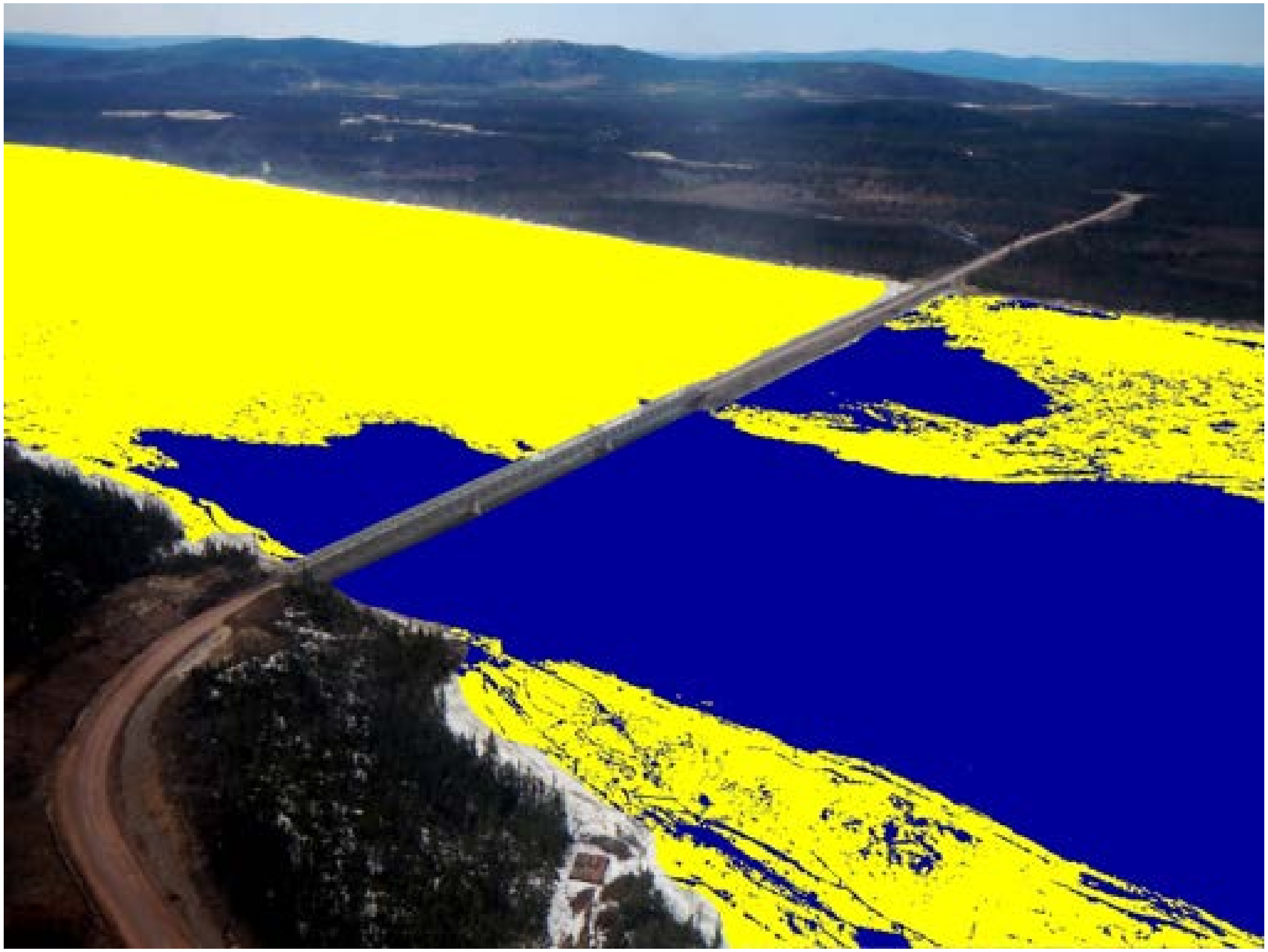
Ice Floe Analyses During Break-up

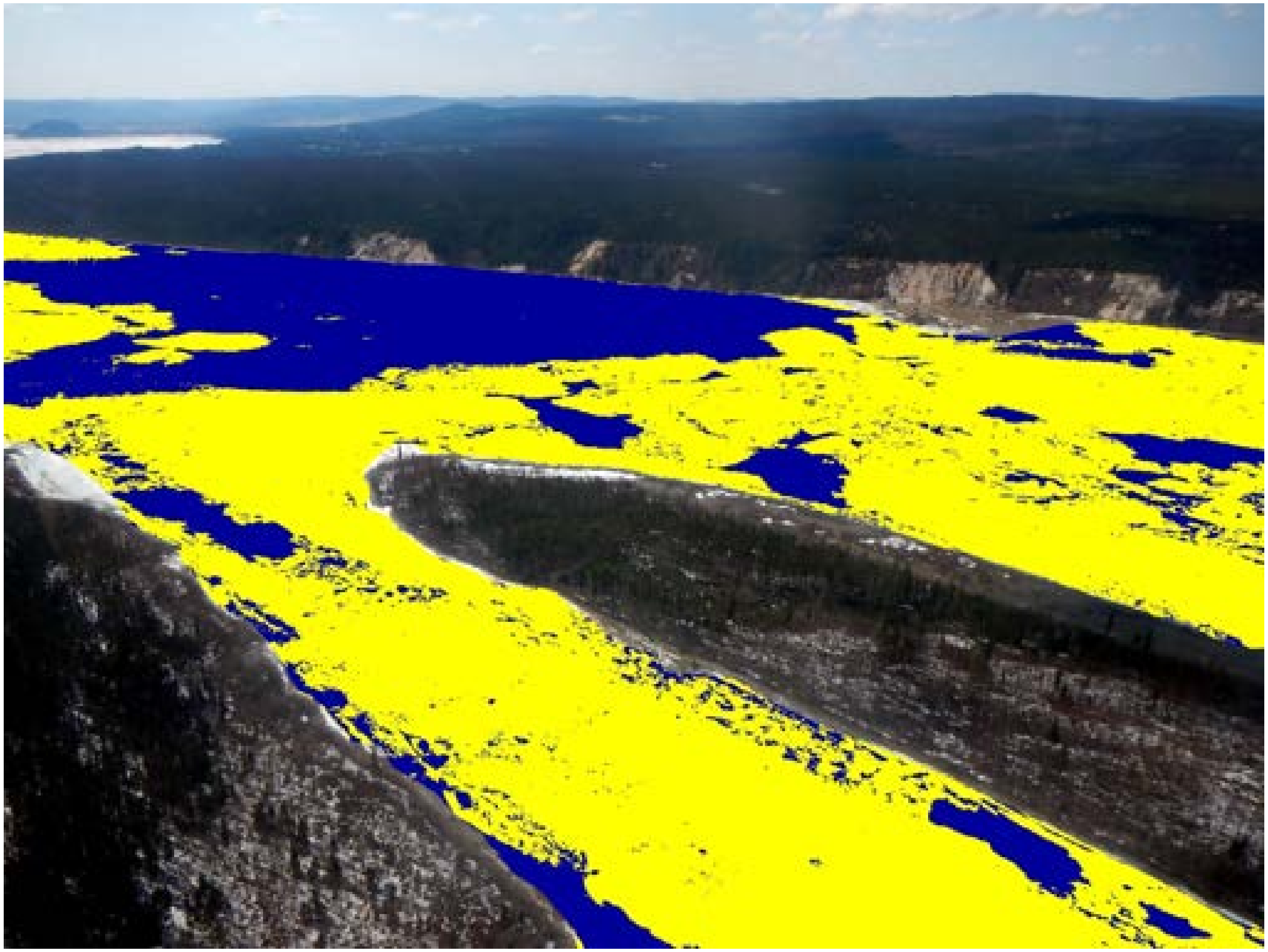
Churchill River - Aerial Photo Analysis 2014-15

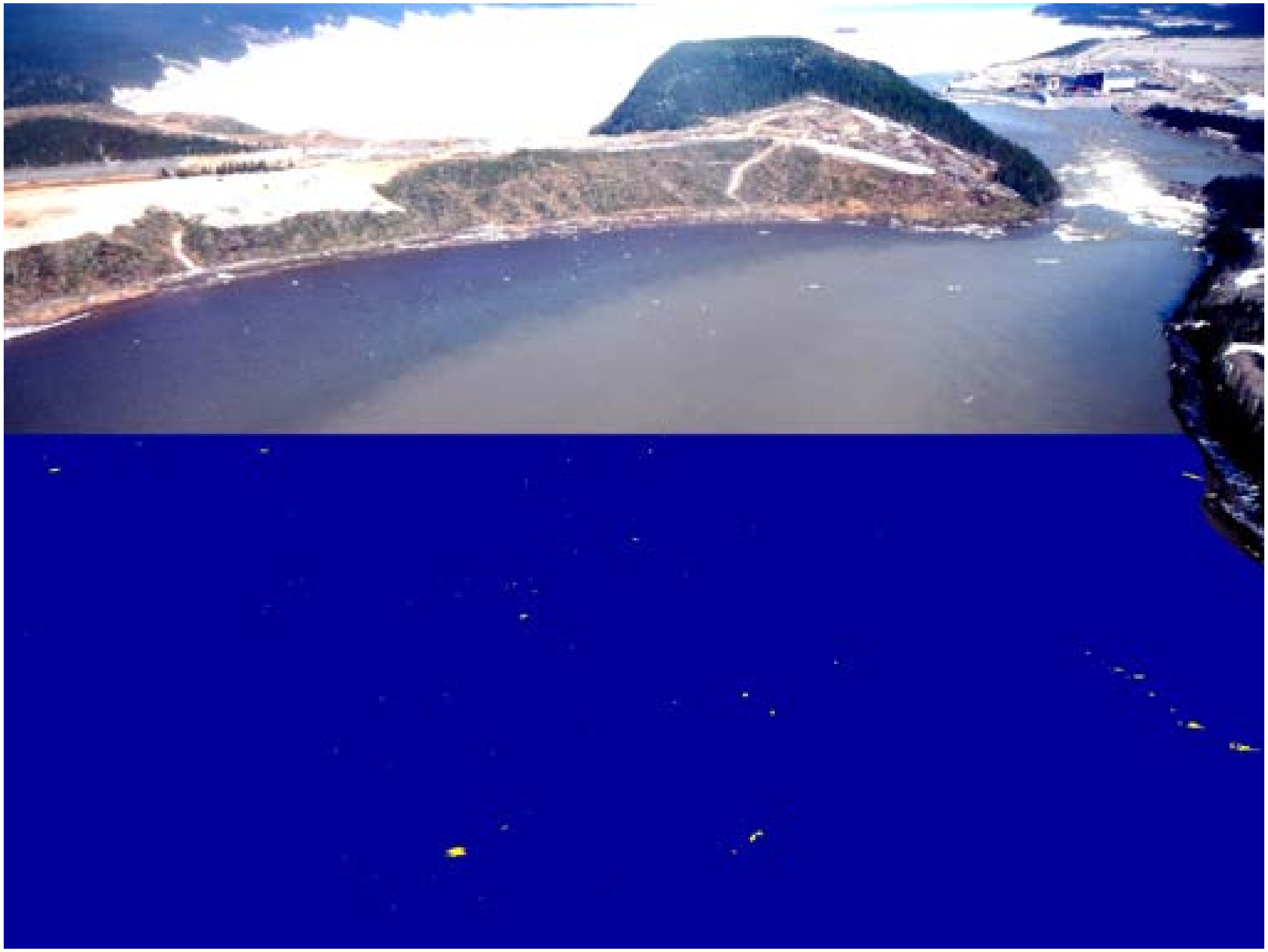


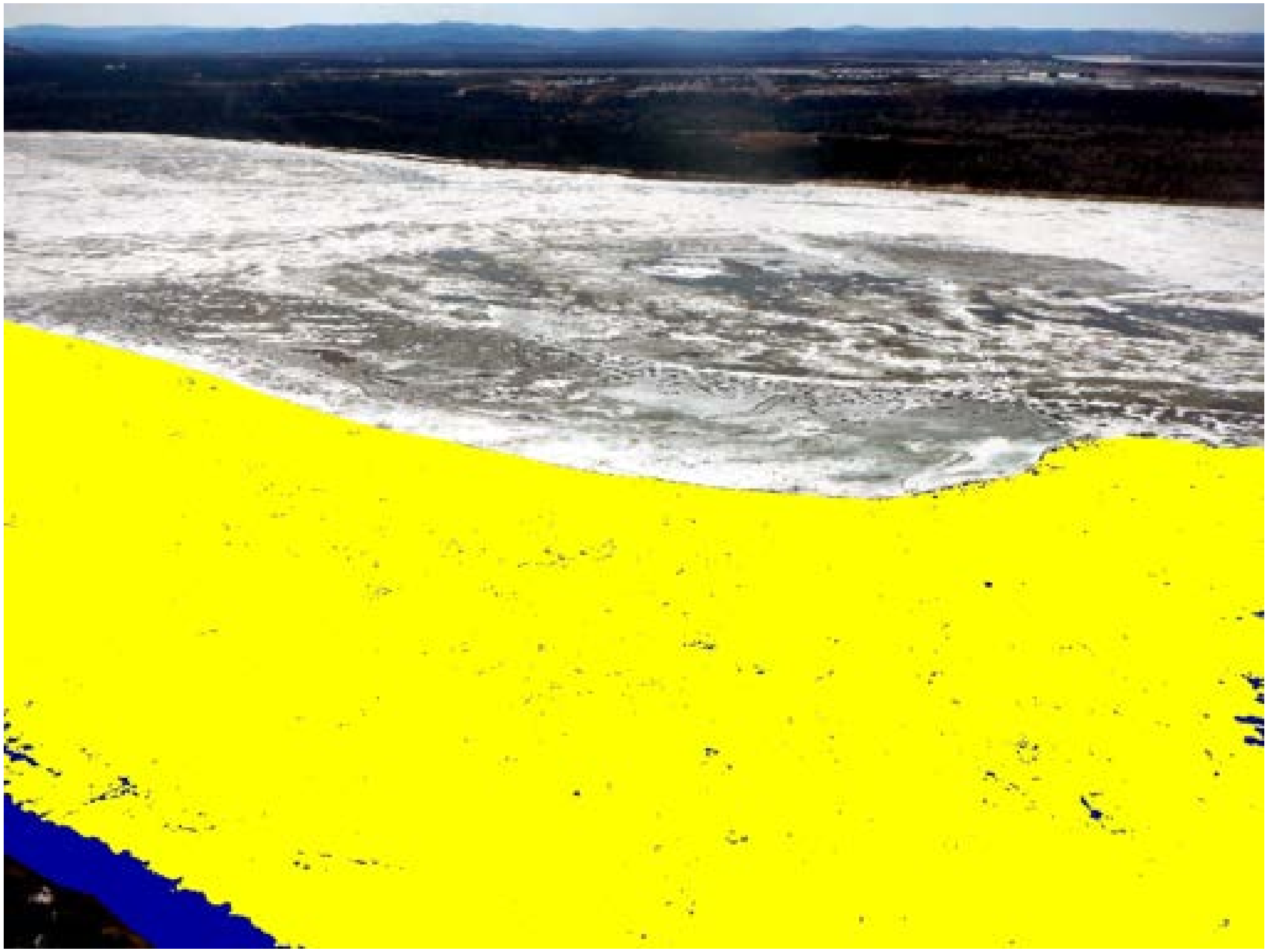


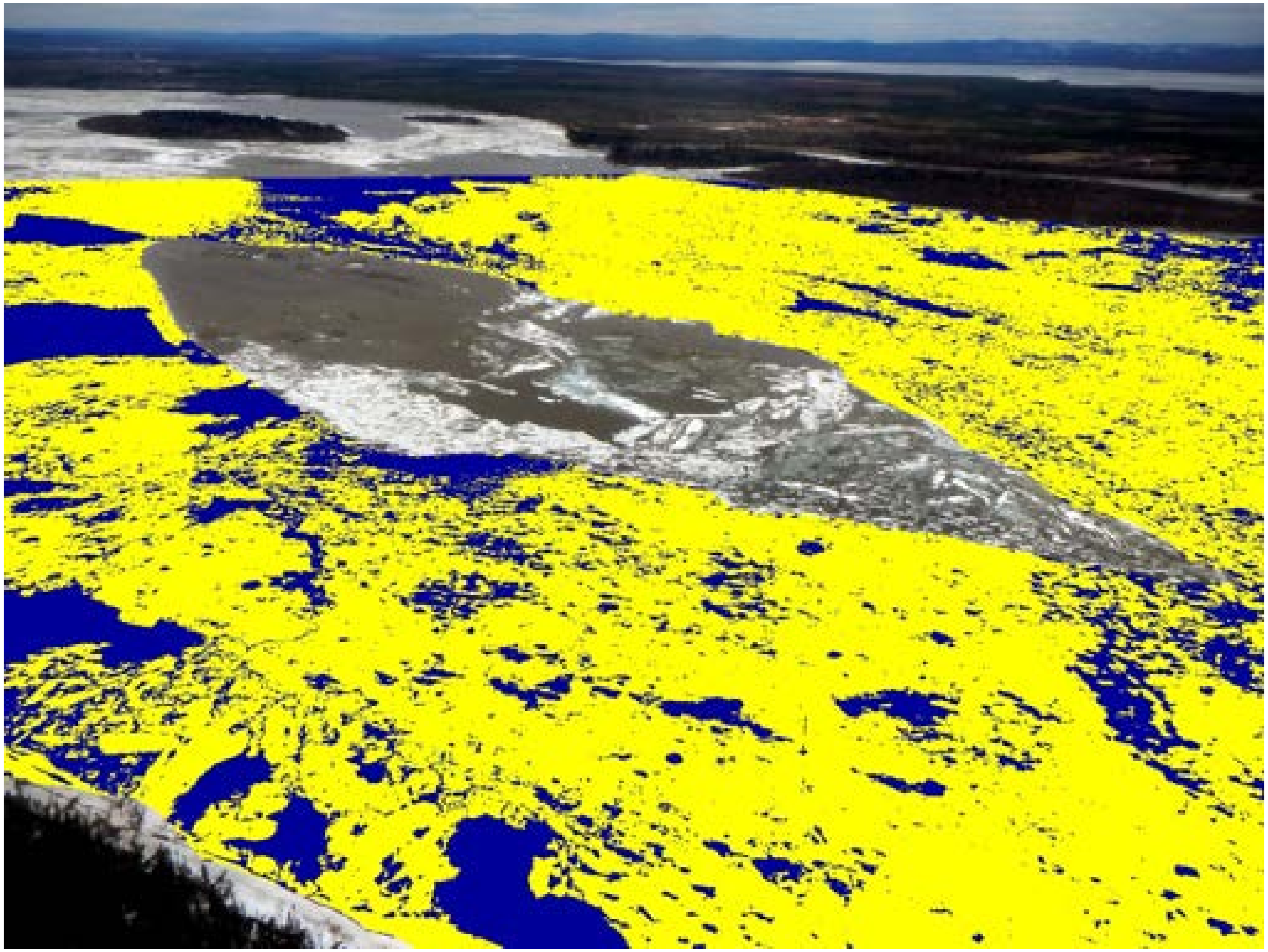


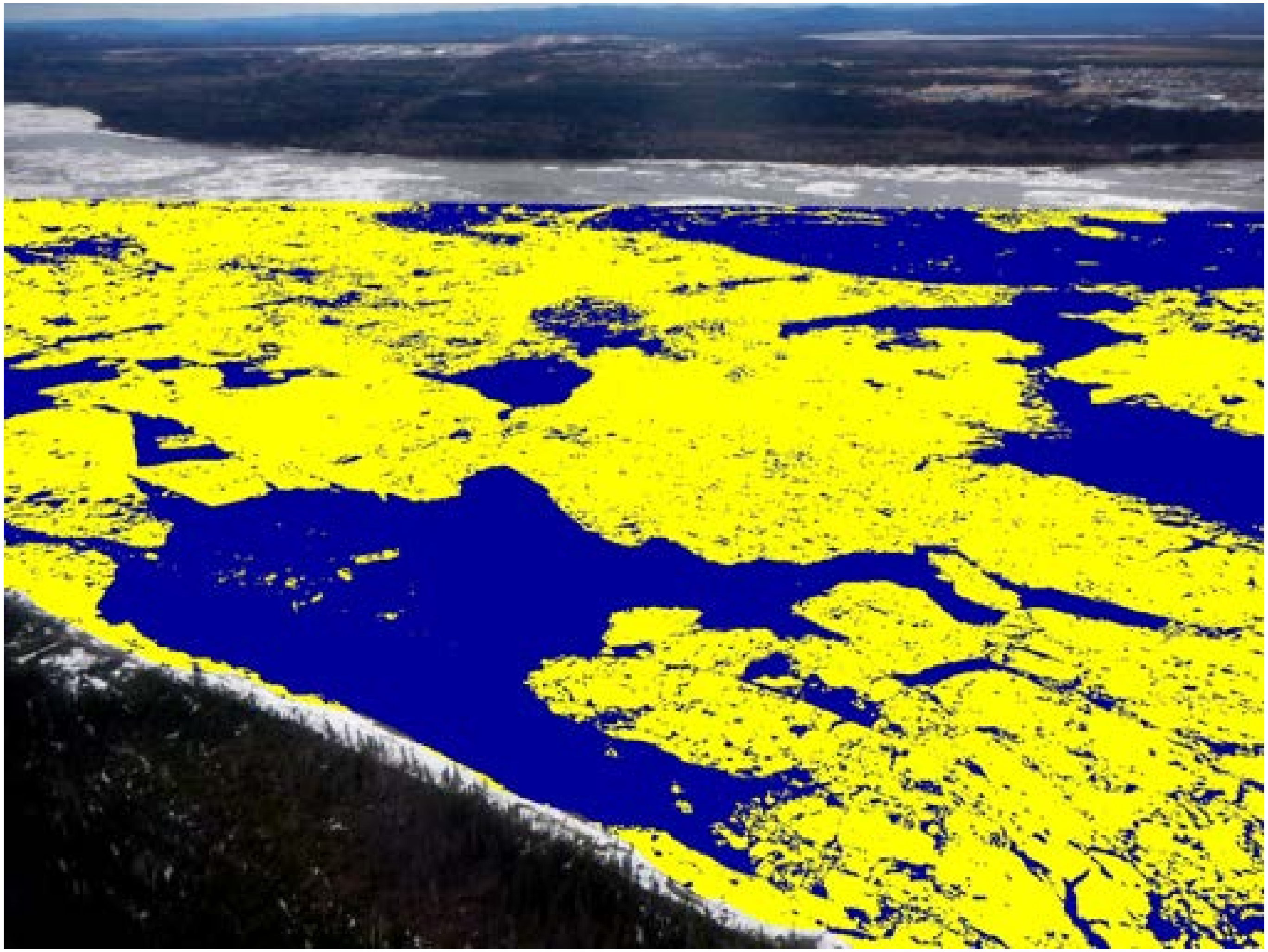


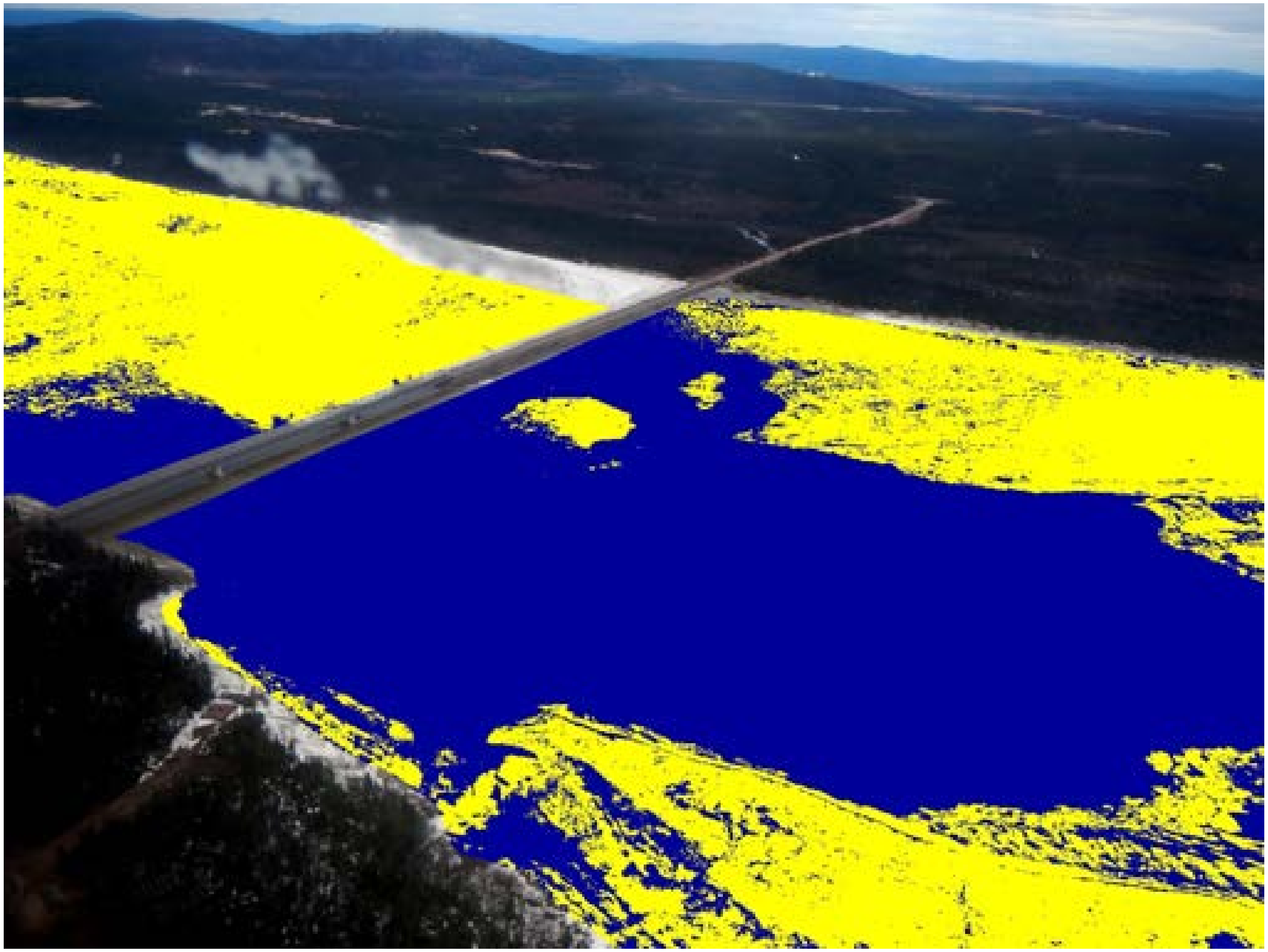


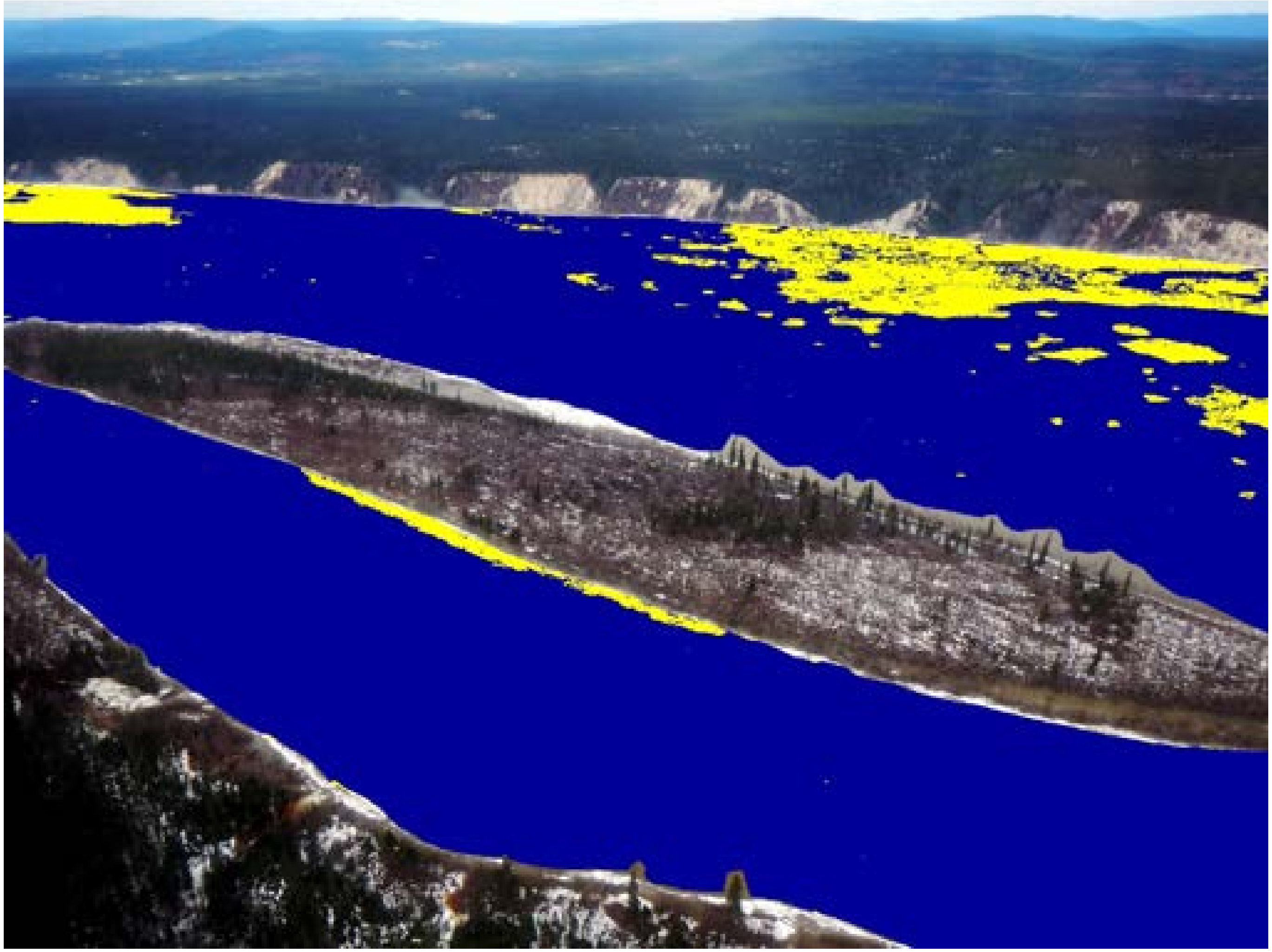


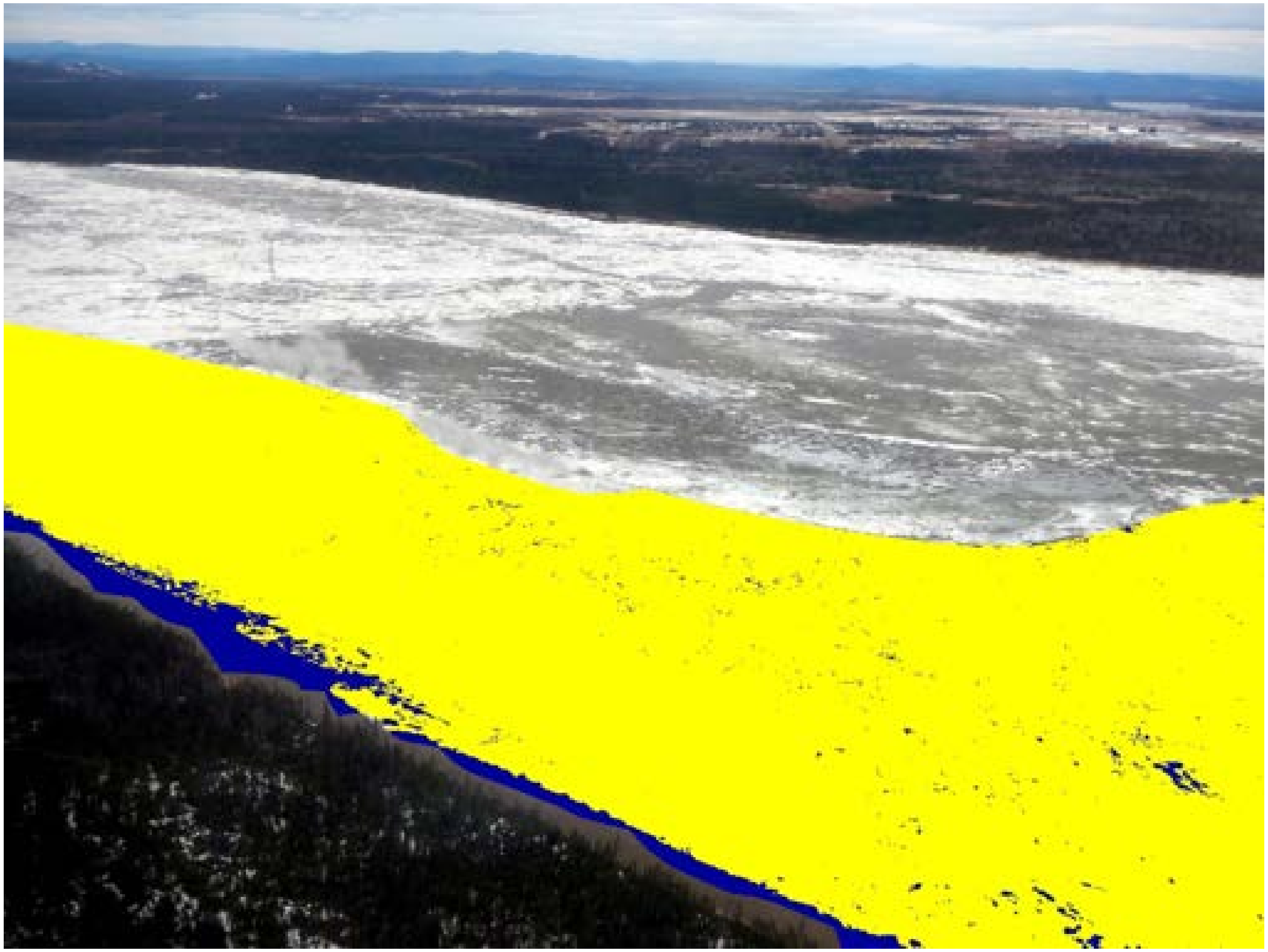


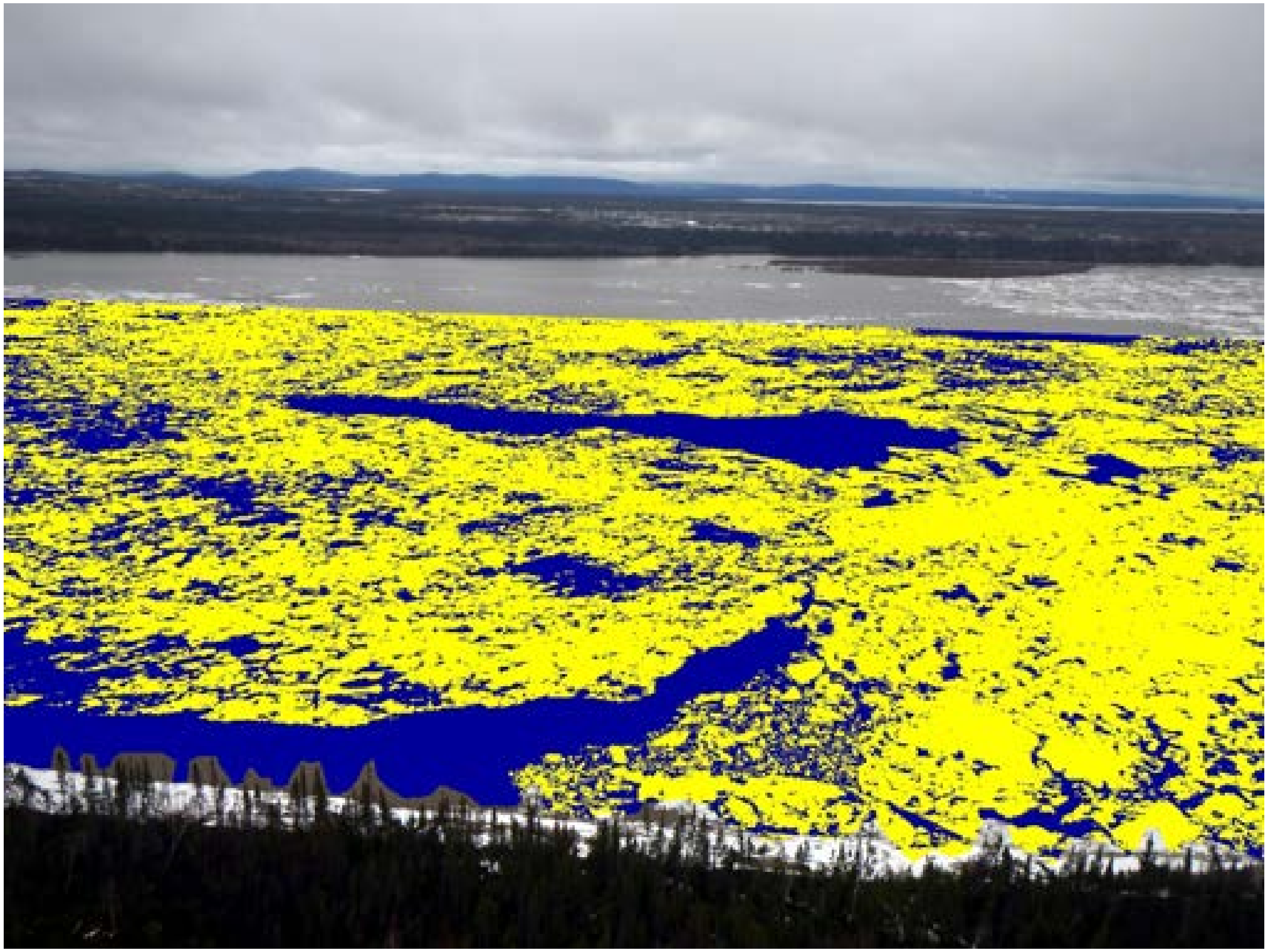


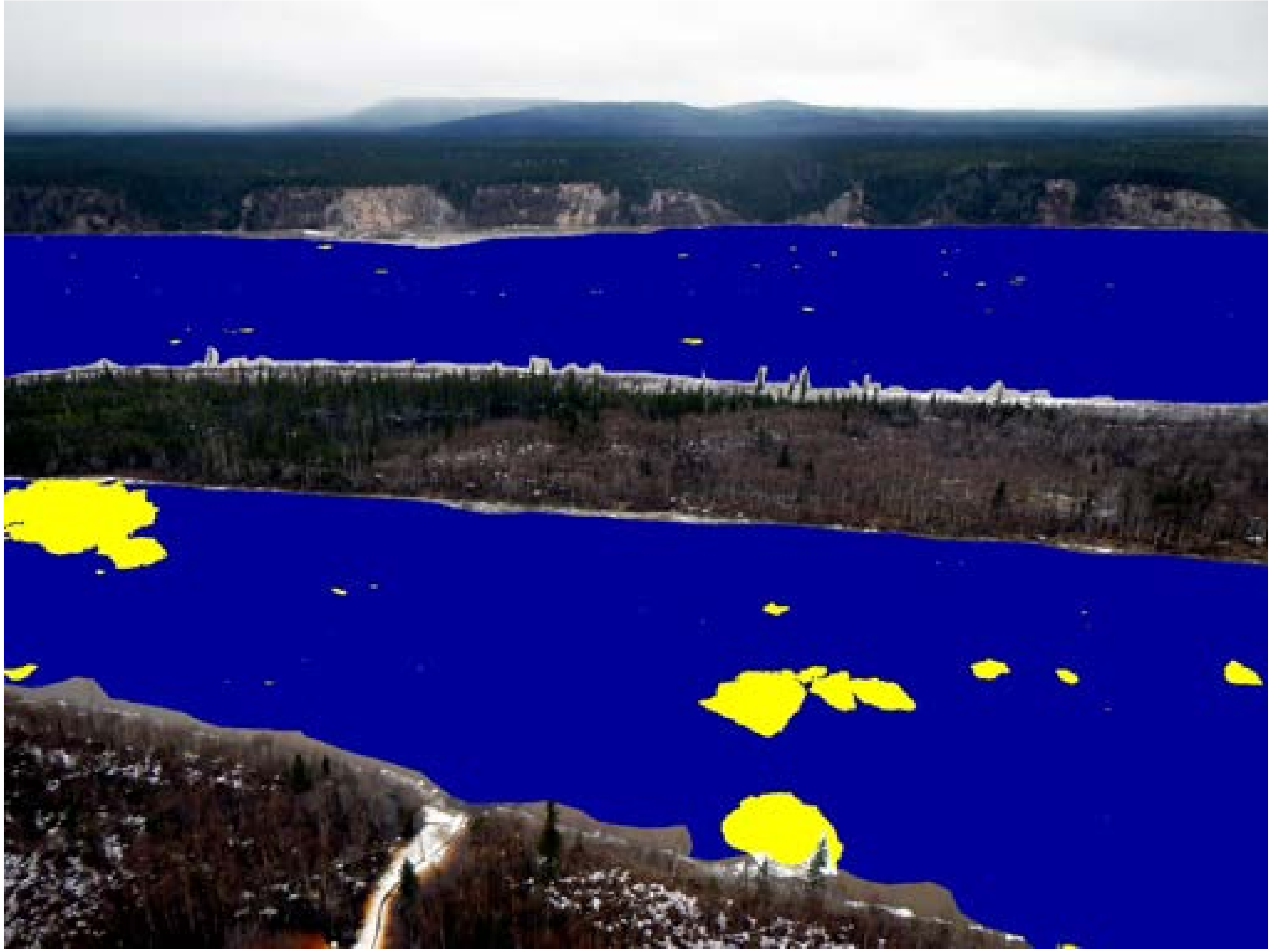












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APPENDIX G

Field Reports for the Aerial Ice Observation Survey

2013-2016 Ice Observation Survey
Mud Lake Crossing, Lower Churchill River
LC-EV-107

Field Program Report 3

Prepared For:

Golder Associates Ltd.
Suite 204, 62 Pippy Place
St. John's, NL
A1B 4H7

Prepared By:

Sikumiut Environmental Management Ltd.
SEM
2nd Floor, 79 Mews Place
St. John’s, NL
A1B 4N2

December 15, 2014

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1.0 INTRODUCTION

As part of the regulatory commitments stemming from the Lower Churchill Hydroelectric Generating Project Environmental Impact Statement (EIS), Nalcor Energy has determined that ice studies between Mud Lake and Muskrat Falls must be carried out during project construction to confirm baseline conditions. Sikumiut Environmental Management Limited (SEM) has been retained by Golder Associates Ltd. (Golder) on behalf of Nalcor Energy (Nalcor), Lower Churchill Project (NE-LCP) to conduct an ice survey of the Lower Churchill River, between Muskrat Falls and Mud Lake, during freeze-up and break-up processes. The work included an aerial ice observation survey using a Global Positioning System (GPS) camera with georeferenced photographs being taken from a helicopter, and collection of ice cores across the Mud Lake ice bridge from the north bank of the Lower Churchill River to Mud Lake after ice formation. SEM sub-contracted the Center for Cold Ocean Research and Engineering (C-CORE) to analyze and interpret the data collected during the study, including radar satellite image interpretation and analysis, ice floe concentration analyses, and modeling of river ice thickness. Hatch Ltd. (Hatch) was sub-contracted to complete hydrological modeling of volumetric flow rate of ice. The aerial survey was completed during the freeze-up and break-up periods, while the ice coring was conducted during the freeze-up period only, and the radar satellite imagery was collected throughout the ice season.

NE-LCP has been observing ice processes on the Lower Churchill River since 2006. Historical surveys were conducted in the 1980s and 1990s by various parties. The purpose of the current studies was to improve the understanding of river ice processes such that they could be considered in the design and construction of the generation facilities of the Muskrat Falls and Gull Island sites, as well as to allow for predictions of ice conditions throughout project construction and beyond. This program is important to the residents of Mud Lake, a community located downstream of Muskrat Falls, who rely on the Churchill River as their transportation link to Happy Valley–Goose Bay.

2.0 OBJECTIVES

The objectives of the field trips were to:

- Complete an aerial ice observation survey to document by photography the freeze-up process; and to aid in determining the upstream effect of the NE-LCP on downstream ice formation.

- Complete an ice thickness survey, using augering techniques, at set intervals along the Mud Lake ice crossing for documentation and comparison to previous and future years.

2.1 Study Team

Aerial Ice Observation Survey (November 22-25, 2014)

Patrick Hamlyn, Field Lead

Robyn Bradley, Field Team

Ken Cashin, Pilot, Universal Helicopters Newfoundland Limited (Universal)

Ice Thickness Survey (February 9-10, 2015)

Stefan Cahill, Field Lead

Brad Vaters, Field Team

Randy Best (Mud Lake Resident), Field Team

3.0 LOCATION

The aerial ice observation survey took place between Mud Lake and Muskrat Falls (Figure 3.1).

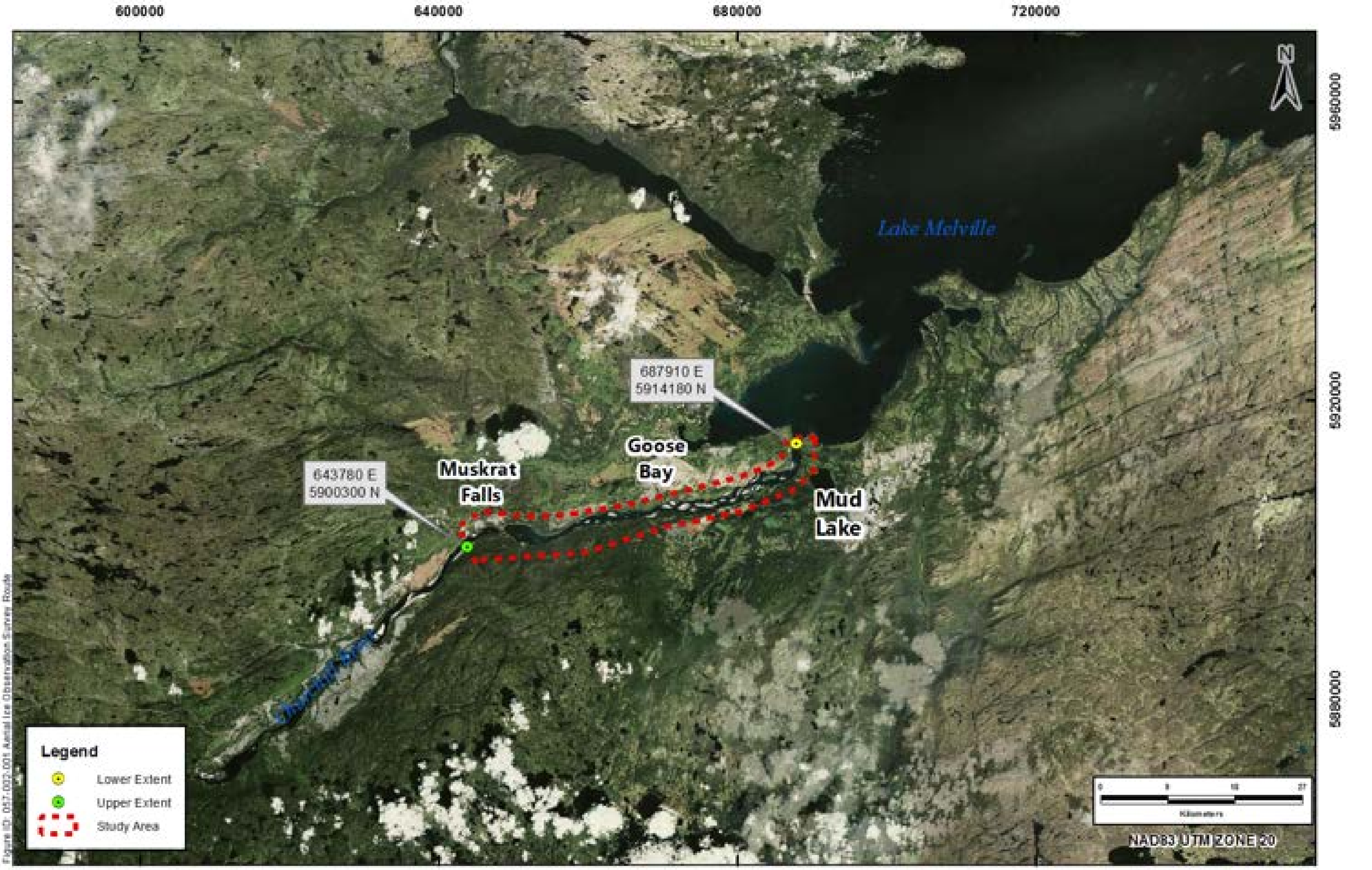


Figure ID: 057-007-001 Aerial Ice Observation Survey Route

Golder Associates	Lower Churchill Ice Observation Studies	PREPARED BY SEM
FIGURE NO. 3.1	Project Location Map	DATE: 15/12/2014

4.0 EQUIPMENT

- Nikon Coolpix AW110 GPS camera
- Garmin GPSmap 76CSx handheld GPS
- Bell 206 Long Ranger Helicopter (Universal)
- Ice Auger
- Ice Pick
- Snowmobile

5.0 SAFETY PLAN

Refer to SEM (2013), '2013-2016 Ice Observation Survey Program, Health and Safety Plan, LC-EV-107'. Prepared for Golder Associates Ltd., St. John's, NL. ii + 33 pp, + 10 appendices.

6.0 FIELD PROGRAM

The field program for the NE-LCP aerial ice observation survey took place from November 22 to 25, 2014 while the ice thickness survey was completed on February 9 and 10, 2015.

6.1 Aerial Survey

The aerial survey was performed to capture photographs from a side view across the river and from bank to bank looking downstream. These photos were then processed back in the office to document the freeze-up period.

6.1.1 Pre-Mobilization

The pre-mobilization stage included the following:

1. On November 17, SEM began monitoring daily mean air temperatures at the Happy Valley–Goose Bay weather station for comparison with historical weather data patterns. SEM also observed photos taken by the Mud Lake web cam, found on the Newfoundland and Labrador Department of Environment and Conservation (NLDEC) website.

2. On November 1, SEM began communications with Randy Best, a Mud Lake resident, who has monitored the freeze-up and break-up processes at Mud Lake for more than 30 years.

3. SEM mobilized the field team and started the field program on November 22, 2014.

6.1.2 Day 1

The field team arrived in Happy Valley–Goose Bay on November 22, 2014 and conducted the first survey. Crew left the Universal hanger to collect the first set of aerial photographs for the aerial ice observation survey at 13:55. Weather conditions were good, with clear, sunny skies and an air temperature of -10 degrees Celcius (°C), with winds from the west at 20 km/h. A Bell 206 Long Ranger helicopter (C-FCWR), chartered from Universal, was used for all survey work (Figure 6.1).

Figure 6.1 Bell 206 Long Ranger (C-FCWR).

SEM initially conducted a toolbox safety meeting, followed by a detailed helicopter safety briefing provided by the pilot, Ken Cashin. The field team then departed from the Universal hanger at 13:55 and proceeded to fly to Mud Lake. The helicopter then flew along the southern bank of the Lower Churchill River and the SEM team took continuous side view photographs from Mud Lake to Muskrat Falls at approximately 300 meters above sea level (masl). An example of the side view photos is provided in Figure 6.2.

On the return trip, the helicopter took a route down the center line of the river and SEM took photographs across the river, from bank to bank, in the same general locations as the previous survey, or if the field team deemed an area needed to be captured at approximately 300 masl. An example of a bank to bank photograph is provided in Figure 6.3. GPS locations where logged along the route at each photograph location to provide consistency between photos during the survey of the ice freeze-up and again during break-up. The two types of aerial photos (side view and bank to bank) were taken to ensure overlap, such that the entire extent of the river was captured. Once back at Mud Lake, more photographs were taken along the delineated ice crossing route.

Figure 6.2 Photo from Southern Bank (Side View).

Figure 6.3 Photo from the Central Route (Bank to Bank).

The field team arrived back at 15:05 using 1.1 hours of flight time and safely waited for the aircraft to be shut down. After the flight, the team held a post-flight meeting with the pilot to plan the following day's flight and discuss the data collected.

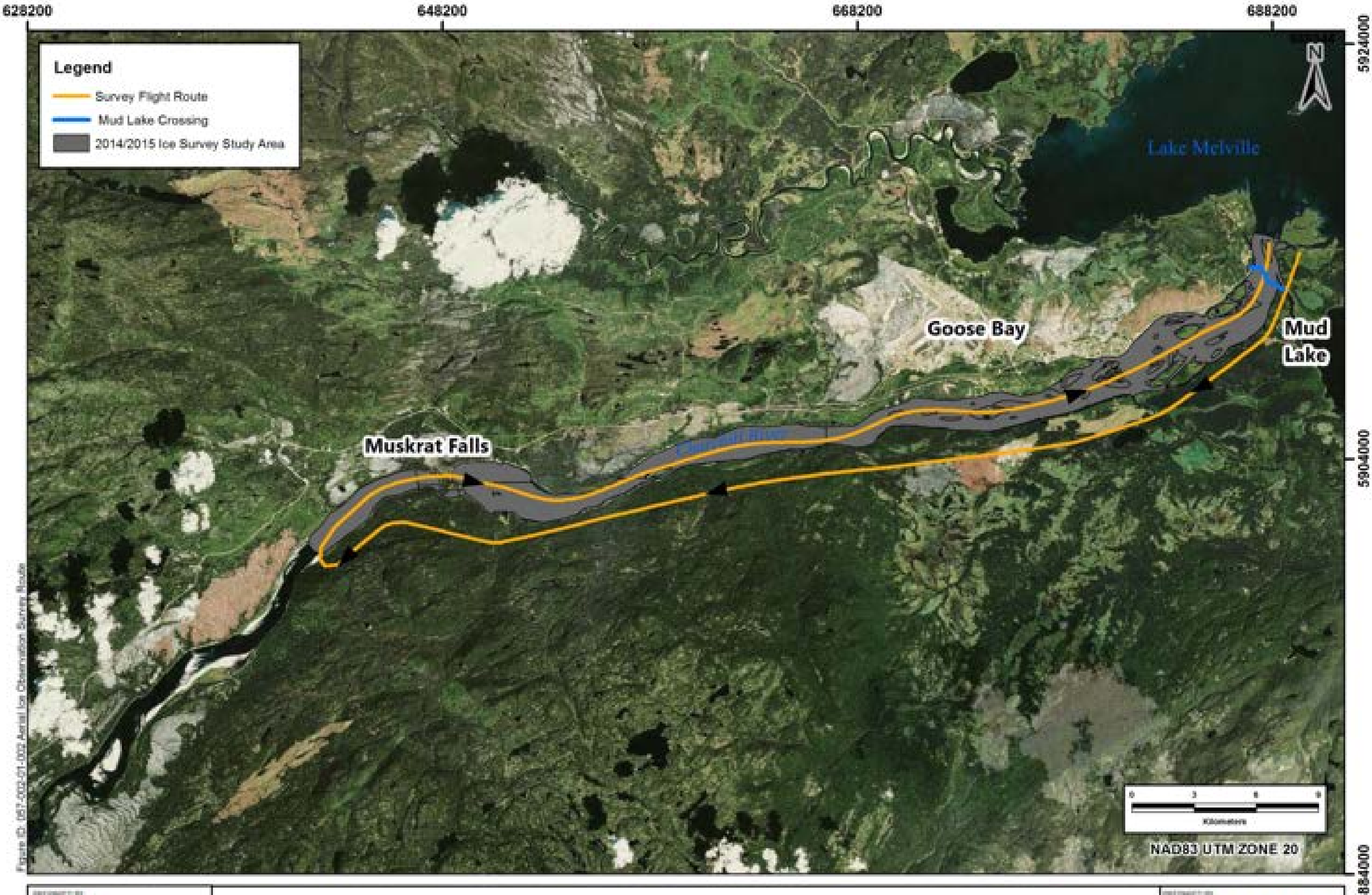
That evening, the field team processed all photographs taken that day to determine if any alterations may be required in the protocols used for the aerial ice observation survey and to determine if total coverage of the Lower Churchill River had been achieved. A telephone call was made with SEM's Project Manager to provide an update on the flight, and current ice and weather conditions in the area.

It was apparent from the field data and observations that the ice near Mud Lake was beginning to form. Although not passible by snowmobile at this point, it was apparent the complete freeze-up was expected to occur soon. This was discussed and it was determined that the field team would monitor the ice over the upcoming days and report on the status to SEM's Project Manager. It was also determined that the protocol and waypoints used had captured the freeze-up process in its' entirety from Mud Lake to above Muskrat Falls, and this same procedure would be used out throughout the survey.

6.1.3 Day 2

The field team arrived at Universal' hanger on November 23, 2104, and departed at 12:12 to perform the second aerial ice observation survey. Weather conditions were good with a mix of sun and cloud and a temperature of approximately -7 °C, with winds WNW at 15 km/h. The field team followed the same protocol as used on the first day. A toolbox safety meeting was conducted by the field team, followed by a detailed helicopter safety meeting by the pilot, Ken Cashin.

The field team then flew to Mud Lake and followed the same route as the previous day, up the southern bank of the Lower Churchill River from Mud Lake to above Muskrat Falls, and then returning down the centre line of the river back to Mud Lake maintaining an altitude of 250 to 300 masl (see Figure 6.4). Once back at Mud Lake, more photographs were taken along the delineated ice crossing route (see Figure 6.5). The field team arrived back at the Universal hanger at 13:12 after using a total of 1.1 hours of flight time. A post-flight meeting was held with the pilot to plan for the next day.



Golder Associates	**Lower Churchill Ice Observation Studies**	SEM
6.4	AERIAL OBSERVATION SURVEY ROUTE	**12/08/2015**

Figure 6.5 Mud Lake Ice Crossing.

The field team processed all data collected for the first two flights. It was noted that the ice seemed more competent and a suitable, safe snowmobile crossing could soon form. A telephone call between field lead and the SEM Project Manager was made to provide an update of weather and ice conditions. The Project Manager advised that the survey timing was appropriate for freeze-up and to continue with the scheduled surveys.

6.1.4 Day 3

The field team arrived at the Universal hanger at 12:00 and a toolbox safety meeting was held followed by a helicopter safety briefing from pilot Ken Cashin. At the time of departure, the weather was -12°C and clear with wind from the southwest at 10 km/h. The same survey protocols were followed as the previous two surveys and the helicopter maintained an altitude between 250 to 300 masl. The field team returned to Mud Lake and took overlapping photos along the length of the ice crossing at a larger scale to get a detailed view of the ice along the crossing route.

The condition of the ice near Mud Lake had improved and snowmobiles had begun crossing, from Mud Lake to Happy Valley–Goose Bay. It was noted that Mud Lake residents were out on the ice marking the trail with spruce tree tops for the season as done in previous years (see Figure 6.6).

Figure 6.6 Mud Lake Ice Crossing.

The field team arrived back at the Universal hanger at 13:15, having used 1.1 hours of flight time. The team held a meeting with the pilot and determined that one additional flight may be needed. Universal agreed to accommodate the additional flight and a time to fly the next survey was agreed upon.

The field team processed all data collected that day and had a telephone conversation with the SEM Project Manager. The field team was advised to conduct an additional observation survey to ensure the complete documentation of the freeze-up process.

6.1.5 Day 4

The field team arrived at the Universal hanger at 11:30, a toolbox safety meeting was held, followed by a helicopter safety briefing from the pilot. At the time of departure, the weather was 2°C with rain and the winds were from the southwest at 27 km/h. The same survey protocols were followed as used for the first three days and the helicopter maintained an altitude between 250 to 300 masl.

The field team returned to Mud Lake and took photos to document the condition of the Mud Lake ice crossing. The condition of the ice near Mud Lake still appeared competent (Figure 6.7) and one snowmobile was crossing at the time of the survey.

Figure 6.7 Mud Lake Crossing Overview from the South Bank.

The field team arrived back at the Universal hanger at 12:50, having used 1.1 hours of flight time. At the SEM Goose Bay office, the photos were processed for all data collected that day. After the processing, a telephone conversation was held between field staff and the SEM Project Manager. It was determined that the freeze-up had been fully documented and the field team would return to St. John's.

6.2 Ice Thickness Survey

The ice thickness survey was completed to take measurements of the ice along the Mud Lake ice crossing. These ice thickness measurements were collected to allow comparison with previous and future years to determine any trends in ice formation at this location.

Ice augering techniques were carried out, with all the safety protocols in mind, to drill a hole in the ice which was then measured and recorded. The holes were augered at predetermined locations to cover the full extent of the crossing while avoiding areas where sandbars were present.

6.2.1 Pre-Mobilization

The pre-mobilization stage included the following:

1. On February 2, SEM determined that the ice at the Mud Lake ice crossing was in a solid state and safe to carry out the necessary ice work. SEM used the previous month's weather forecast, the Mud Lake web cam and the knowledge of a local resident (Randy Best) for this determination. It was decided that the survey would take place the following week.

2. SEM tested all the applicable gear, including a new 6" auger, to ensure that all equipment was in good working order. The equipment was then shipped via Provincial Airlines (PAL) cargo, on February 5 to Goose Bay.

3. SEM mobilized the field team and started the field program on February 9, 2015.

6.2.2 Day 1

The field team arrived at Goose Bay Airport on February 9, 2015 and retrieved the equipment from PAL Cargo and brought everything to SEM's Goose Bay office to prepare for the next day.

The field team tested all equipment to ensure it was in good working order. This included visual inspections of safety gear and augers, as well as testing the required mechanical gear, particularly the auger engine. This was required to that ensure the equipment could be operated efficiently and safely in extreme cold conditions. Upon completion of the inspection, a trip to a local supplier to purchase additional tools and supplies (e.g. lubricants) was undertaken.

The field team then returned to the SEM office, made contact with the field assistant from Mud Lake, Randy Best, and made arrangements to meet at the Goose Bay landing site of the Mud Lake crossing the following morning at 08:00.

The snowmobile and sled, rented from a local Goose Bay resident, were picked up that evening to ensure the team was ready to go first thing in the morning. Rental of the snowmobile and sled from a local resident was required because commercial rentals in Goose Bay were not available.

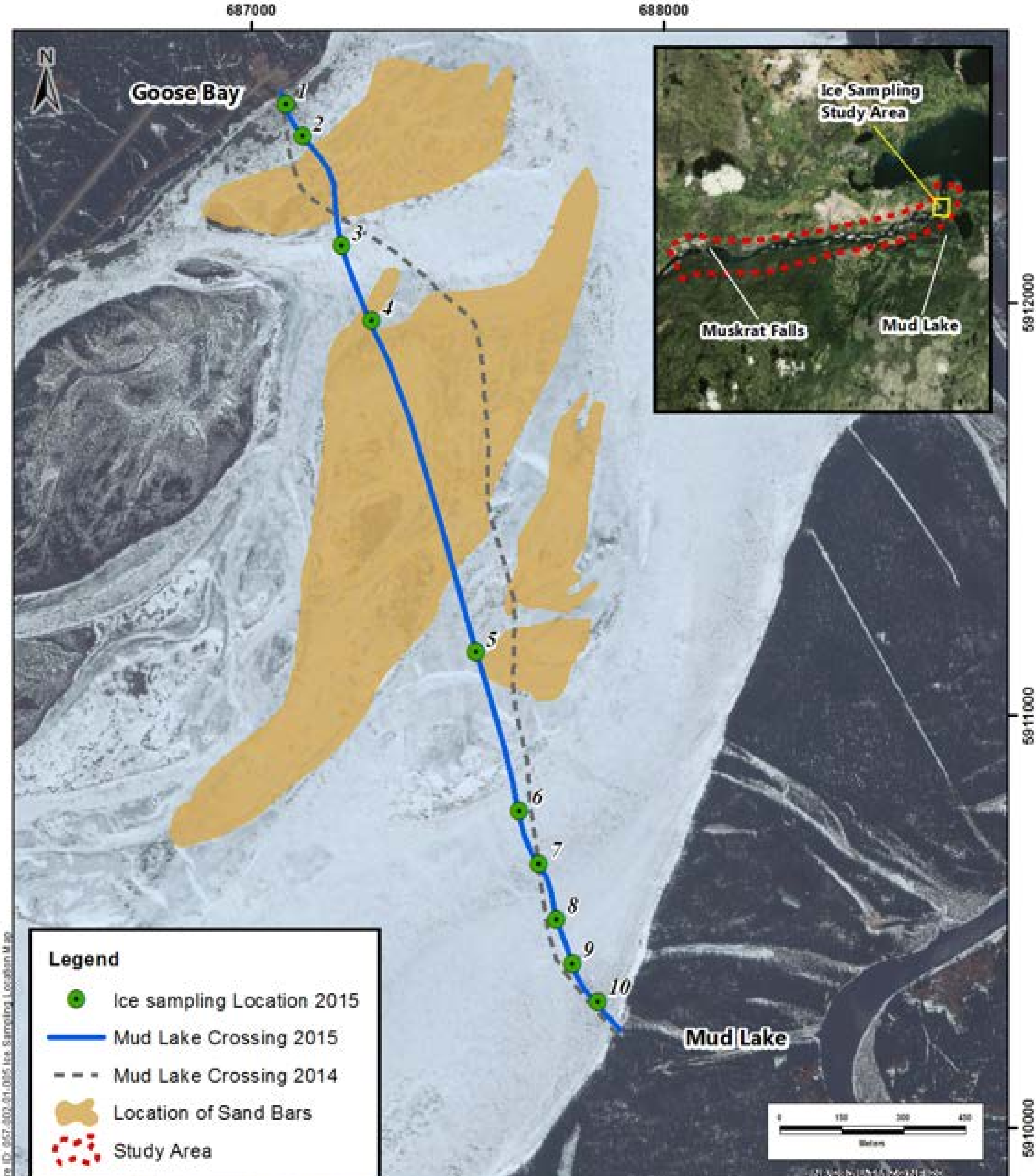
6.2.3 Day 2

On the morning of February 10, the field team proceeded to the SEM office to load the equipment onto a truck. The team then travelled to the landing site on the Northern side of the Mud Lake ice crossing. Arriving at 08:00, they met with Mud Lake resident Randy Best. The weather for the day was mainly sunny and cold (-30 °C) with 10 km/hr winds from the south.

Upon arrival at the Mud Lake crossing, safety gear including cold weather apparel was donned and a tail gate safety meeting was held. A number of issues were discussed including snowmobile use, cold weather safety, auger use as well as any other general safety considerations. The field team then unloaded the snowmobile and sled from the truck and hitched up the sled to the snowmobile.

After discussing the work scope with Randy Best, the field team proceeded to the crossing and augered holes at ten locations along the crossing (Figure 6.8) and recorded the required ice thickness data. The augering locations had been pre-determined from the 2013-2014 ice crossing route and were uploaded to a Garmin GPSmap 76CSx handheld unit. In several cases the locations drilled were different than those that had been pre-selected owing to differences in the route selected in 2014-2015 in comparison to that used in 2013-2014. In these cases, the field team selected the alternate location based on intervals of approximately 250 m in length, and in consideration of Randy Best's knowledge of the selected crossing route. Randy Best's involvement in this survey was critical as he was aware where the sandbars were located and was able to identify suitable locations that were close to the crossing but in an area that was a safe distance away from the route being used by public travellers.

The ten ice sampling locations were along the Mud Lake ice crossing route, which is approximately 2.5 kilometres (km) in length. The ice thickness varied from 70 to 118 centimetres (cm) with most auger holes having solid ice throughout, with the exception of one hole located just off the south bank of the river (Ice Sampling Location 10, Figure 6.8), which had a layer of slush 20 cm thick on top of the ice. All holes were snow covered with thickness ranging from 65 to 100 cm. All data collected is provided in Table 6.1.



Golder Associates

Lower Churchill Ice Observation Studies

SEM

FIGURE NO:		DATE:
6.8	Ice Sampling Location Map	03/05/2014

Table 6.1 Ice Studies Data Sheet.

Nalcor - Ice Studies Data Sheet				
Test Hole ID	Easting	Northing	Depth (cm) Snow/Slush/Ice	Notes

Date:	**Comments:**
Client:	-
Project:	
Location:	
Projection:	
Completed By:	
Field Crew	
1)	
2)	
3)	
4)	

7.0 LESSONS LEARNED AND RECOMMENDATIONS

This is the second year of a three year ice study program, therefore, it is important to identify and learn from any issues that arose to assist in planning and completion of future ice surveys. There is always room for continuous improvement to increase effectiveness and success of future programs. Issues noted on this field trip are discussed below:

1. **Capturing the Freeze-up Period**

   It is challenging to adequately capture the exact freeze-up of the Churchill River near the Mud Lake ice crossing. The process happens rapidly and, with the requirement for flights and travel arrangements, there is a short window for this survey which could be easily missed. The NLDEC webcam was monitored daily and a local Mud Lake resident was routinely consulted, both of which assisted in providing an accurate timing for the surveys. It should be empasized, however, that the precise timing of the freeze-up process is very difficult to determine and planning and monitoring needs to be in place to ensure a meaningful survey.

2. **GPS Signal**

   As noted in the previous aerial ice observation survey, the Nikon GPS camera would occasionally lose GPS signal due to interference from the helicopter, as well as the horizontal positioning of the satellites at any given time. The field team easily corrected this issue by ensuring a GPS fix before every photograph was taken. Since this issue had been previously identified, the field team was diligent in ensuring this issue was addressed. If the signal was lost, the crew would hold position at that location and continue with the survey once the signal was re-gained.

3. **Predetermined Ice Sampling Locations**

   Due to the yearly shift in the Mud Lake ice crossing route, as well as the sand bars within the Lower Churchill River, it is difficult to pre-determine ice sampling locations. Initially it was planned to do the sampling at the same locations each year. Although this approach seems possible on the South side of the river, these factors vary more on the North side where sand bars are more prevalent and dynamic from year to year. In future surveys, the sampling points from the previous year will only be used as a guide to help determine the likely sampling points for the following year. SEM will continue to sample in the same location as the previous year, where the conditions allow, and the field team will rely on the Mud Lake resident's knowledge to determine the appropriate sampling locations.

2013-2016 Ice Observation Survey
Mud Lake Crossing, Lower Churchill River
LC-EV-107

Field Program Report 4

Prepared For:
Golder Associates Ltd.
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SEM
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May 19, 2015

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

As part of the regulatory commitments stemming from the Lower Churchill Hydroelectric Generating Project Environmental Impact Statement (EIS), Nalcor Energy has determined that ice studies between Mud Lake and Muskrat Falls must be carried out during project construction to confirm baseline conditions. Sikumiut Environmental Management Limited (SEM) has been retained by Golder Associates Ltd. (Golder) on behalf of Nalcor Energy (Nalcor), Lower Churchill Project (NE-LCP) to conduct an ice survey of the Lower Churchill River, between Muskrat Falls and Mud Lake, during freeze-up and break-up processes. The work included an aerial ice observation survey using a Global Positioning System (GPS) camera with georeferenced photographs being taken from a helicopter, and collection of ice cores across the Mud Lake ice bridge crossing from the north bank of the Lower Churchill River to Mud Lake after ice formation. SEM sub-contracted the Center for Cold Ocean Research and Engineering (C-CORE) to analyze and interpret the data collected during the study, including radar satellite image interpretation and analysis, ice floe concentration analyses, and modeling of river ice thickness. Hatch Ltd. (Hatch) was sub-contracted to complete hydrological modeling of volumetric flow rate of ice. The aerial survey was completed during the freeze-up and break-up periods, while the ice coring was conducted during the freeze-up period only, and the radar satellite imagery was collected throughout the ice season.

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2.0 OBJECTIVES

The objective of the spring ice break-up field program was to:

- Complete an aerial ice observation survey to document, by using photography, the ice break-up process; and to aid in determining the upstream effect of the NE-LCP on downstream ice break-up.

2.1 Study Team

Claire More-Gibbons, Field lead

Robyn Bradley, Feld team

Wayne Massie, Dean Burry, Darren Walsh, helicopter pilots at Canadian Helicopters (Canadian)

3.0 LOCATION

The aerial ice observation survey took place between Mud Lake and Muskrat Falls (Figure 3.1).

Figure ID: 057-002-001 Aerial Ice Observation Survey Route

Golder Associates	**Lower Churchill Ice Observetion Studies**	PREPARED BY SEM
FIGURE NO **NAD83 UTM ZONE 20**	Project Location Map	DATE **03/01/2014**

4.0 EQUIPMENT

- Nikon Coolpix AW110 GPS camera
- Garmin GPSmap 78s handheld GPS
- A-Star 350 Helicopter (Canadian)
- Bell 206 Long Ranger Helicopter (Canadian)

5.0 SAFETY PLAN

Refer to SEM (2013), '2013-2016 Ice Observation Survey Program, Health and Safety Plan, LC-EV-107'. Prepared for Golder Associates Ltd., St. John's, NL. ii + 33 pp, + 10 appendices. *Updated May 2015.*

6.0 FIELD PROGRAM

The 2015 ice break-up field program for the NE-LCP ice observation study took place from May 17 to 19, 2015.

6.1 Aerial Survey

6.1.1 Pre-Mobilization

The pre-mobilization stage included the following:

1. All field team members completed Fit-For-Work medical assessments and a five-panel drug and alcohol screening test as part of the NE-LCP ice observation study.

2. On April 20, SEM began monitoring the daily mean air temperatures at the Happy Valley–Goose Bay weather station. SEM also observed photos taken by the Mud Lake webcam, found on the Government of Newfoundland and Labrador's Department of Environment and Conservation website.

3. In May, SEM began communications with Jordan Hope, a Mud Lake resident, who has monitored the freeze-up and break-up process at Mud Lake for more than 30 years.

4. SEM mobilized its field team and started the field program on May 17, 2015.

6.1.2 Day 1

The field team arrived in Happy Valley–Goose Bay at approximately 14:00 on May 17, 2015, and proceeded directly to the Canadian hanger to perform the first set of aerial photographs for the aerial ice observation survey. Weather conditions were good with clear, sunny skies and an air temperature of 19 degrees Celcius (°C), with winds from the southwest at 37 km/h. An A-Star 350 helicopter (C-GTPF), chartered from Canadian, was used for survey work (Figure 6.1).

Figure 6.1 A-Star 350 Helicopter (C-GTPF).

SEM conducted a toolbox safety meeting which was followed by a detailed helicopter safety video and a briefing provided by the pilot, Wayne Massie. The field team then departed from the Canadian hanger at 15:15 and proceeded to fly to Mud Lake (at the mouth of the Churchill River). The helicopter then flew along the southern bank of the Lower Churchill River and the SEM team took continuous side view photographs from Mud Lake to Muskrat Falls at approximately 250 metres above sea level (masl). An example of the side view photos is provided in Figure 6.2. On the return trip, the helicopter took a route down the centre line of the river and SEM took downstream photographs across the river, from bank to bank, in the same general locations as the previous survey using waypoints loaded into the handheld Global Positioning System (GPS) device. An example of a bank to bank photograph is provided in Figure 6.3. The centre line photos were taken at the same altitude as the side view photographs (~250 masl.). GPS locations were tagged to the centre line photos along the route at each location to ensure consistency between photos during the survey of the ice break-up and again during freeze-up. The two types of aerial photos (side view and centre line bank to bank) were taken to ensure overlap such that the entire extent of the river was captured. Figure 6.4 demonstrates the flightpath for the side view and centre line photographs. Once back at Mud Lake, photographs were taken at 150 masl along the delineated crossing area (Figure 6.5).

Figure 6.2 Photo from Southern Bank (May 17, 2015 Mud Lake Crossing) (Side View).

Figure 6.3 Photo From Central Route (May 17, 2015 near Muskrat Fall) (Bank to Bank).

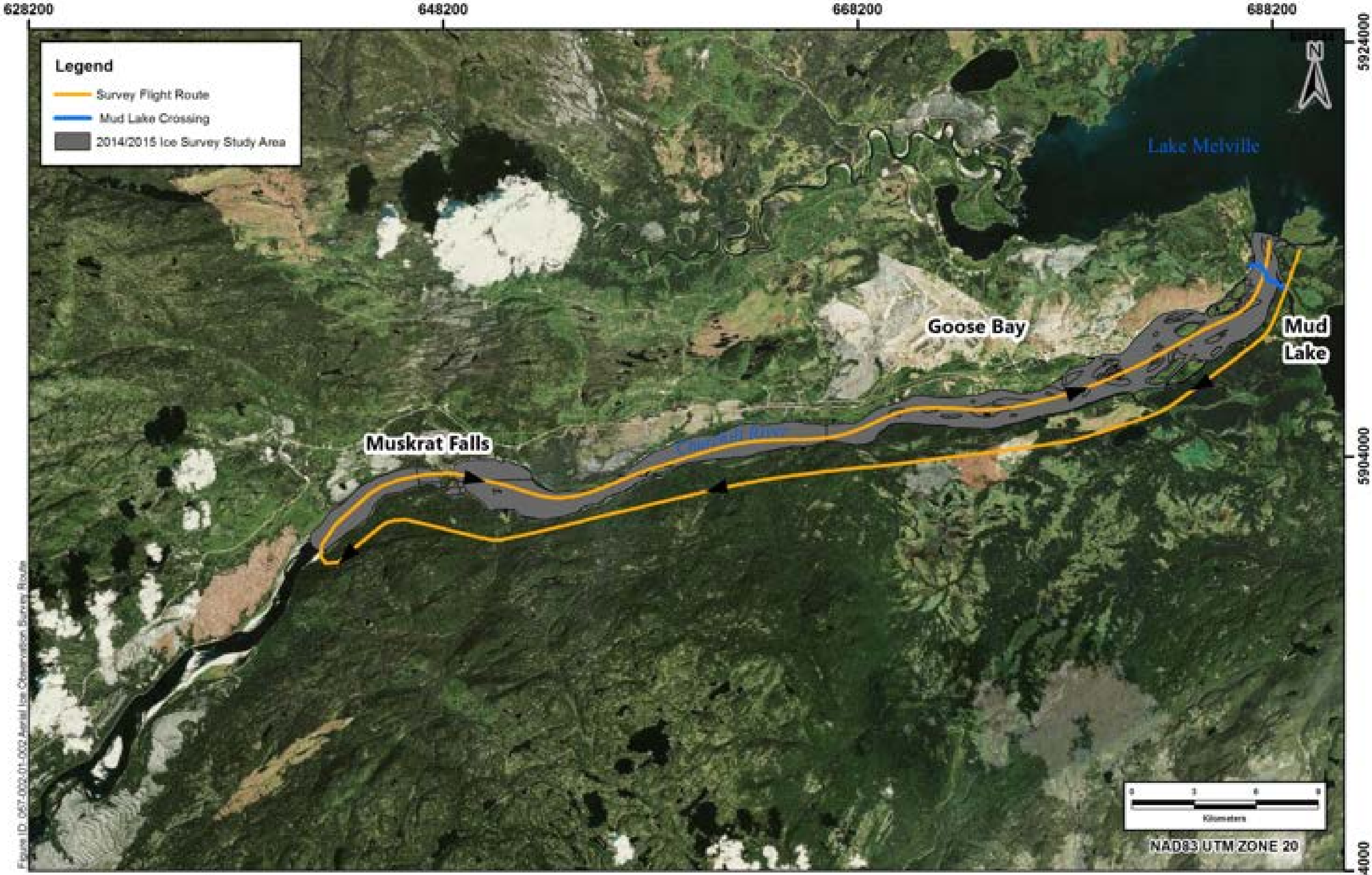

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Figure 6.5 Mud Lake Ice Crossing (May 17, 2015).

The field team arrived back at 16:30 using 1.3 hours of flight time and safely waited for the aircraft to shut down. After the flight, the team held a post-flight meeting with the pilot to plan the next day's flight and discuss the data collected.

That evening, the field team processed all photographs taken that day to confirm that geo-referencing of photographs had been successful. The team also reviewed photographs to determine if any alterations may be required to the protocols used for the aerial ice observation survey and to determine if total coverage of the reach of the Lower Churchill River had been achieved. A summary of activities was sent to the SEM office to update an update on ice conditions. It was apparent from the field data and observations that the ice near Mud Lake was progressing towards break-up and was likely a couple days away. It was determined that the protocols and waypoints used had captured the appropriate aerial coverage to display the ice break-up process in its' entirety from Mud Lake to Muskrat Falls, and this same procedure would be carried out throughout the survey. Due to the type of helicopter used, photographs had to be taken through an unopened window; however, this did not affect the quality of the images obtained.

6.1.3 Day 2

The field team arrived at the Canadian hanger on May 18, 2015 and departed at 12:20 to perform the second aerial ice observation survey. Weather conditions were good, with overcast skies, and a temperature of approximately 14°C, with winds from the west (280°) at 17 km/h. The field team followed the same protocols as used on the first day, except that the detailed safety briefing was not repeated. A toolbox safety meeting was conducted by the field team, followed by a detailed helicopter safety meeting by the pilot, Dean Burry. An A-Star 350 helicopter (C-GBPS), chartered from Canadian, was used for survey work (Figure 6.6).

Figure 6.6 A-Star 350 Helicopter (C-GBPS).

The field team then flew to Mud Lake and followed the same route followed the previous day, up the southern bank of the Lower Churchill River to Muskrat Falls, and then returning down the centre line of the river back to Mud Lake, maintaining an altitude of 300 to 350 masl. Once back at Mud Lake, detailed photographs were taken along the delineated crossing area (Figure 6.7).

Figure 6.7 Mud Lake Ice Crossing (May 18, 2015).

The field team arrived back at the Canadian hanger at 13:40 after using a total of 1.3 hours of flight time. A post-flight meeting was held with the pilot to plan for the next day.

The field team processed all data collected for the first two flights. It was noted that there was already some change in the ice conditions from the previous day's survey.

6.1.4 Day 3

The field team received a telephone call from Canadian advising them of poor flying conditions due to a low and fluctuating ceiling of 150 to 250 masl. The field team arrived at the Canadian hanger to discuss flight options and flight safety with the pilot (Darren Walsh). It was determined that the flight would be delayed until the conditions improved, which was estimated for approximately 14:00. The field team remained on standby, awaiting the pilot's decision to begin the survey. At approximately 13:00, the pilot indicated that conditions had improved and a flight could take place; however, the altitude would have to be maintained at 150 masl. Upon arriving at the Canadian hanger, a toolbox safety meeting was held followed by a helicopter safety briefing from the new pilot (Darren Walsh). For this survey, a Bell 206 Long Ranger helicopter (C-FNYQ) was used (Figure 6.8). The flight departed at 13:30 and the sky was overcast and foggy, air temperature was 4°C and winds were northeasterly (60°) at 19 km/h. The same survey protocols used for the first two days were followed, with the exception of the

150 masl altitude, and the helicopter pilot adjusted the speed to ensure that side view photographs were overlapping.

Figure 6.8 Bell 206 Long Ranger Helicopter (C-FNYQ).

The field team returned to Mud Lake and continued to take overlapping photos along the length of the Mud Lake crossing, which was open water (Figure 6.9).

Figure 6.9 Mud Lake Ice Crossing (May 19, 2015).

Most of the survey reach of the Lower Churchill River was open water with the exception of some ice accumulating near the causeway as well as just below Muskrat Falls (Figure 6.10).

Figure 6.10 Break-up Near Causeway (May 19, 2015).

7.0 LESSONS LEARNED AND RECOMMENDATIONS

This is the second year of a three year ice studies program, and therefore it is important to learn from any issues that arose the previous year, and to determine if there are any learning opportunities that could assist in planning and completion of future ice surveys. There is always room for continuous improvement to increase effectiveness and success of future programs. A few issues that were noted on this field trip are discussed below.

1. **Capturing the Ice Break-up Period**

   Ice break-up is not a perfect science and is dependent on many different variables including temperature, winds, currents and also the conditions of the previous winter. It was noted that in previous years it was approximately one week from the time the last snowmobile travelled across the Mud Lake ice crossing, to complete break-up. Some local residents are more cautious and will stop using the crossing before others and this is not the only indicator of an imminent break-up. SEM also noted from local contacts that the Churchill River break up is historically expected to occur 5 to 10 days after the break-up of Goose River. This year, SEM combined all local contact information with temperature and snow cover data, and daily satellite imagery to monitor the progress of ice break-up in the Churchill River. The estimate as to timing of the break-up this year was accurate, and while the same approach will likely be followed in future years, there is no guarantee that the break-up will be captured so precisely in future years.

2. **Lower Altitudes - flexibility due to weather conditions**

   On Day 3, the low ceiling required that the survey be conducted at a lower altitude of 150 masl. This was documented in the field notes and was taken into consideration when comparing resolution of photos taken during the other surveys. However, due to weather conditions, and to capture the ice break-up, the flight had to take place at the lower altitude.

3. **GPS Signal**

   As noted in the previous aerial ice observation surveys, the Nikon GPS camera would, at times, lose GPS signal due to interference from the helicopter as well as the horizontal positioning of the satellites at any given time. This was easily corrected by the field team by ensuring a GPS fix before every photograph. Since this issue had occurred previously, the field team was diligent in ensuring this issue was addressed, and if the signal was lost, the crew would wait at the location until they re-gained signal and then continued with the survey.