The Use of Satellite Imagery for Monitoring Ice Break-up along the Mackenzie River, N.W.T.

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ABSTRACT. The usefulness of satellite imagery for providing comprehensive information concerning break-up of river ice is discussed. For the years 1975-77, dates of break-up along the Mackenzie River derived from satellite images correlated well with the dates noted at six ground stations in the valley. It is suggested that satellite imagery could also be used to study ice break-up along rivers where little or no hydrometeorological data are regularly collected.

RÉSUMÉ. *L'utilisation des images fournies par les satellites dans la surveillance des débâcles des glaces le long du fleuve Mackenzie.* On discute de l'utilité des images fournies par les satellites comme moyen d'information détaillée sur les débâcles des glaces des cours d'eau. Au cours des années 1975-77, les dates des débâcles fournies par images de satellites le long du fleuve Mackenzie correspondaient fort bien avec les dates observées par six stations terrestres situées dans la vallée. On suggère que les images fournies par les satellites pourraient aussi être utilisées pour étudier les débâcles le long de cours d'eau sur lesquels peu ou pas de données hydro-météorologiques sont ramassées régulièrement.

РЕЗЮМЕ. *Использование снимков со спутника для мониторинга вскрытия льда на р. Маккензи.* Обсуждается пригодность снимков со спутника для получения исчерпывающей информации о вскрытии льда на реках. Даты вскрытия льда на р. Маккензи в 1975-77 гг., которые были определены по снимкам со спутника, находились в хорошем соответствии с датами, зарегистрироваными шестью пунктами наблюдения, расположенными в долине. Делается предположение, что снимки со спутника могут использоваться также для изучения вскрытия льда на реках, для которых сбор гидрометеорологических данных или вообще отсутствует, или проводится нерегулярно.

INTRODUCTION

The use of satellite imagery in the study of snow hydrology began with the launch of the first weather satellite TIROS-1 on 1 April 1960. It is evident from previous studies that NOAA (U.S. National Ocean and Atmospheric Administration), and ERTS (Earth Resources Technology Satellite) — now known as Landsat, imagery can be used to determine areal snow cover and runoff (Meier 1973; Barnes *et al.* 1974; Wiesnet 1974; and Rango 1975) and break-up of lake and river ice (Ferguson and Cork 1972; Sherstone *et al.* 1974). Results so far obtained indicate that the imagery is both economic and accurate when used operationally (Barnes *et al.* 1974; Rango *et al.* 1976, 1977). The purpose of the study reported upon below was to investigate applicability of satellite imagery to the forecasting of ice break-up on the Mackenzie River and the consequent changes in its rate of flow, with the possibility of flooding. The river is navigable for the 1,600 kilometres from Great Slave Lake to Mackenzie Bay (Fig. 1), for between five and six months a year. Any increase therefore in the accuracy of forecasting ice break-up would

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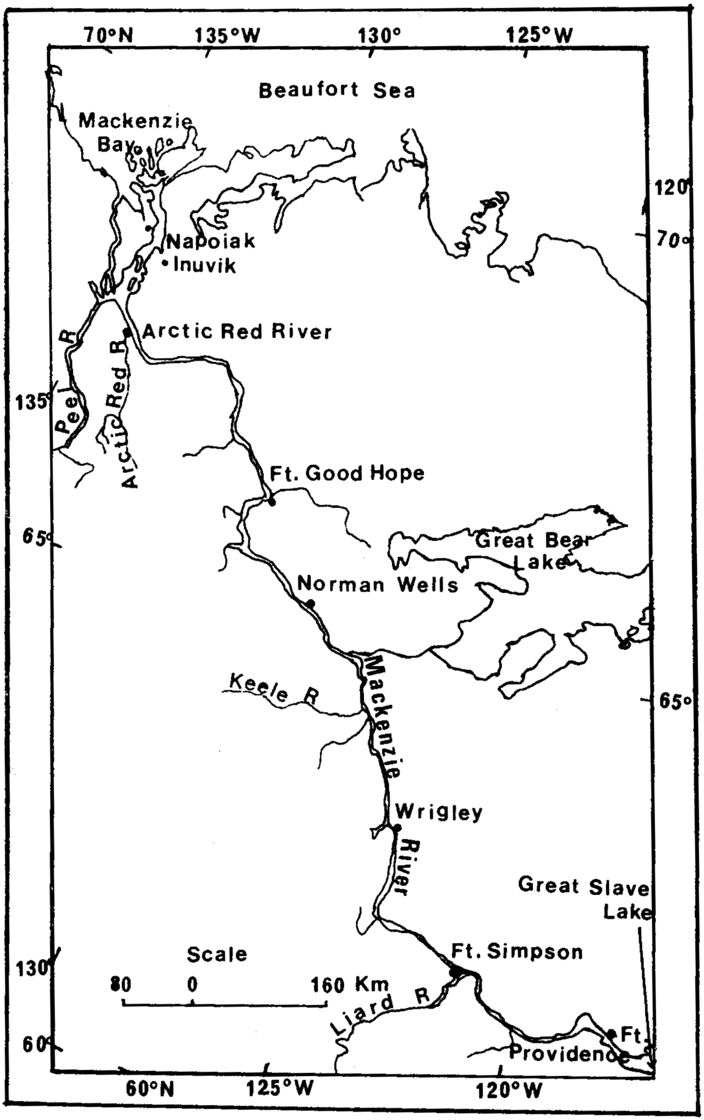

FIG. 1. The study area.

facilitate the scheduling of water transportation which supply centres of oil and gas exploration and local communities during the ice-free period.

TOPOGRAPHY OF STUDY AREA

The Mackenzie Valley, which lies on the leeward side of the Mackenzie Mountains, is of varied topography. It is flat and open between Great Slave Lake and Fort Simpson, and also between Arctic Red River and Mackenzie Bay, but is narrower and deeper between the Franklin and Mackenzie mountain ranges. The constrictions and bends in the river valley have important effects on ice-melt. The river drops in elevation fairly steadily from 156 metres at Great Slave Lake to sea level at the delta and Mackenzie Bay. The upper valley is covered predominantly with forest, the lower with forest and grassland. Tundra vegetation predominates in the delta region.

SOURCES OF DATA

Field observations related to ice break-up were obtained for six stations: Fort Simpson, Wrigley, Norman Wells, Fort Good Hope, Arctic Red River and Napoiak (Fig. 1). Of the six stations, only Wrigley has a data collection platform (DCP). The DCP transmits sensor data from a field site to a satellite (Landsat) which later retransmits to a ground data centre. The Canada Centre for Remote Sensing (CCRS) at Ottawa receives the Canadian DCP data from the U.S. National Aeronautics and Space Administration (NASA) at Goldstone, California or Greenbelt, Maryland after each orbit, with a delay of less than an hour.

METHODOLOGY AND EQUIPMENT

NOAA and Landsat images of the Mackenzie Valley for the period from March through July, 1975 to 1977, were used in this study of break-up.

The NOAA-4 and NOAA-5 environmental satellites provide daily coverage over the study area in the visible (0.6 – 0.7 micrometre) and thermal (10.5 – 12.5 micrometre) spectral bands. The most important of the sensors for hydrological use is the VHRR (very high resolution radiometer). The ground resolution of the

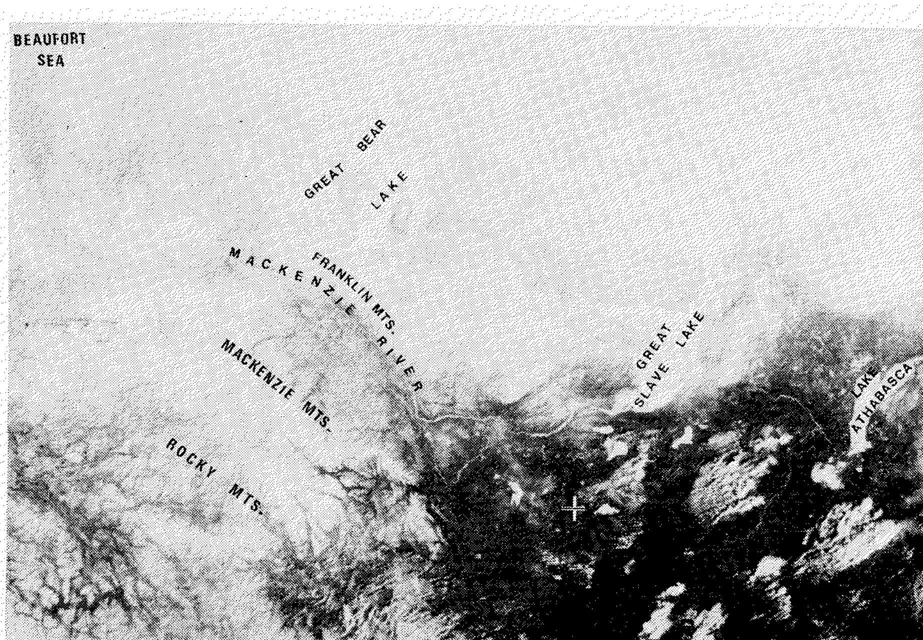

FIG. 2. NOAA image, 1977, before break-up. The frozen Mackenzie River can be seen as a sinuous white line against a black background in the upper valley where snow is melting.

VHRR is one kilometre at nadir. The infrared imagery (10.5 – 12.5 micrometre) of the VHRR can also be calibrated to display radiative surface temperature to an accuracy of ± 1° C and has been applied successfully to synoptic snowmelt monitoring (Barnes *et al.* 1974).

Simple photo-interpretation techniques were used to map the ice conditions on the Mackenzie River, because they are generally straightforward and do not necessitate the use of any elaborate equipment. The NOAA images were in glossy-print form whereas the Landsat images were in microfilm sheet (product known as ISISFICHE). In order that more detailed information might be obtained, the Landsat ISISFICHE images were enlarged with the aid of a projector.

In the NOAA-VHRR imagery, frozen rivers and lakes were identifiable as white sinuous lines or white areas against a background of dark grey to black (Fig. 2). In the absence of ice and snow, water also appeared black and was difficult to distinguish from its background. With Landsat, the frozen and open areas of the Mackenzie River were easily distinguishable one from another as a result of the higher resolution of the imagery. In the band-7 images, the frozen areas were white whereas the ice-free areas were black to dark grey.

RESULTS AND DISCUSSION

Break-up of ice on the Mackenzie River starts east of Fort Simpson (MacKay and Mackay, 1973) and then gradually moves both upstream and downstream. The input of heat and water from the break-up of the Liard River is probably the reason for the opening of the Mackenzie River just east of Fort Simpson. Break-up

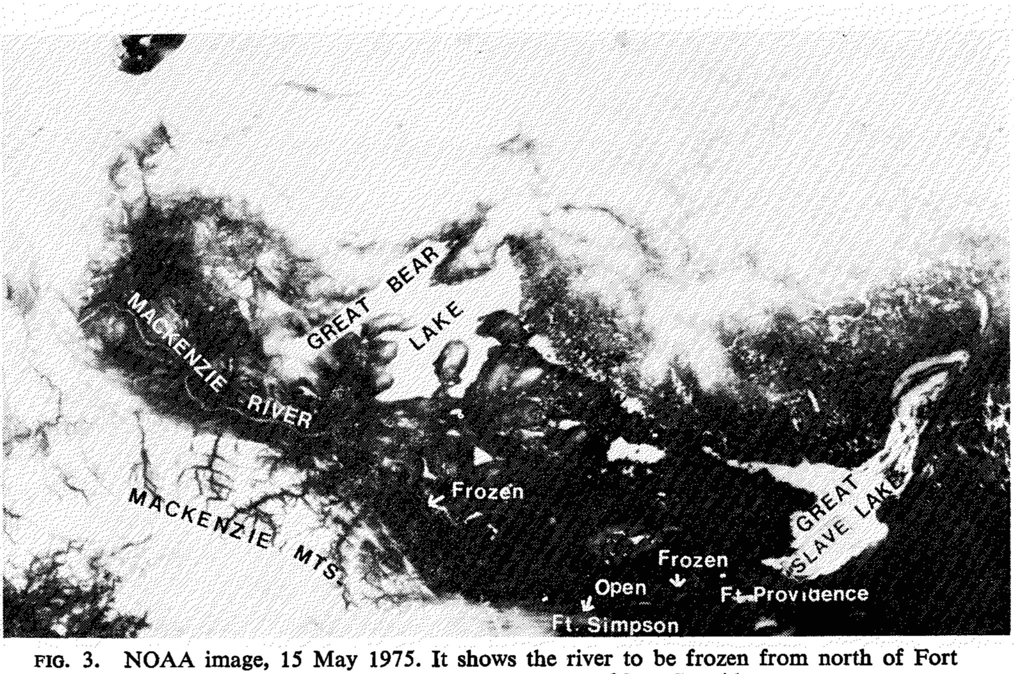

FIG. 3. NOAA image, 15 May 1975. It shows the river to be frozen from north of Fort Simpson to the delta region and also in some areas west of Fort Providence.

TABLE 1. Break-up dates along the Mackenzie River, 1975-77.

Station	1975		1976		1977	
	Satellite imagery	Field observation	Satellite imagery	Field observation	Satellite imagery	Field observation
Fort Simpson	15 May	13 May	7 May	5 May	3 May	4 May
Wrigley	*	*	14 May	16 May	*	11 May
Norman Wells	*	27 May	15 May	12 May	15 May	15 May
Fort Good Hope	4 June	5 June	19 May	*	18 May	17 May
Arctic Red River	*	4 June	24 May	24 May	19 May	21 May
Napoiak	8 June	5 June	26 May	29 May	31 May	29 May

*Not available

is not uniform along the course of the river; there is often open water downstream from areas which are still frozen (Fig. 3). Only satellite imagery can economically detect this type of discontinuous break-up. Progress of break-up for the years 1975, 1976 and 1977 is indicated in Table 1.

In 1975, Landsat-1 imagery was used to document the progress of snowmelt which started in the upper Mackenzie Valley on 6 May and reached the lower areas by 25 May. There was a time lag of about one week between the occurrence of snowmelt in the valley and that of ice break-up on the river which resulted in ice-jams and a rise in the water level. The NOAA imagery of 15 May shows the river to have been frozen from Fort Simpson to the river's delta (Fig. 3) and also indicates some frozen areas near Fort Providence. In 1975, the break-up of ice

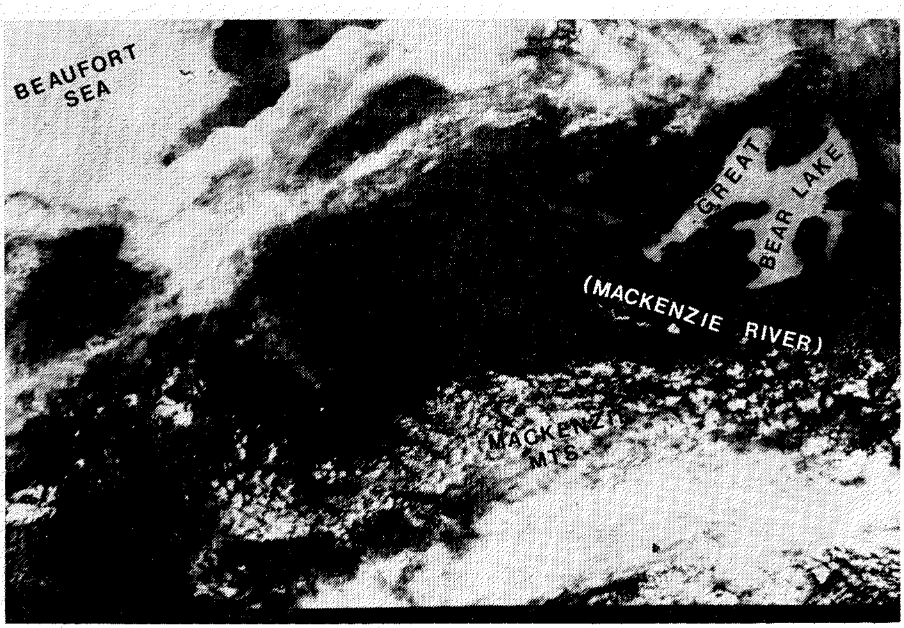

FIG. 4. NOAA image, 8 June 1975. The absence of ice makes the river invisible against the dark background.

on the Mackenzie River was complete by 8 June, as is indicated by the NOAA imagery in Fig. 4. NOAA imagery was used in that year because the transit of Landsat did not coincide with the progress of break-up of river ice.

In 1976, break-up started a few days earlier than in 1975 (Table 1), and its rate was correspondingly faster. Landsat coverage happened to coincide with the progress of break-up and so was very useful in documenting it. Fig. 5 shows the break-up of ice in the lower valley of the Mackenzie River. The NOAA imagery was used to supplement the Landsat.

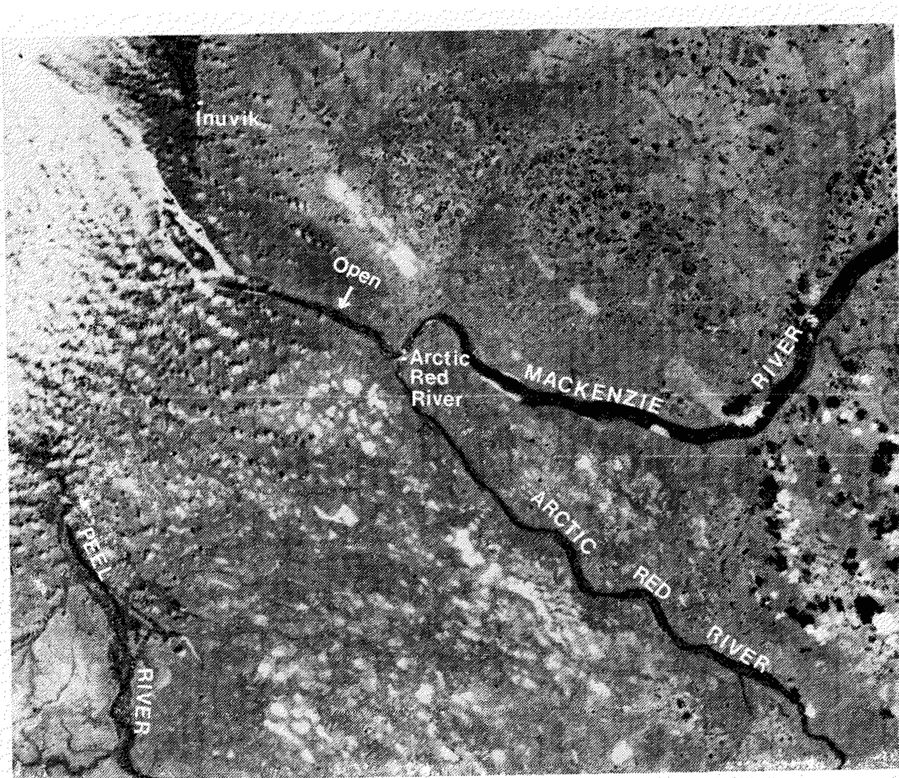

FIG. 5. Landsat (Band 7) image, 24 May 1976. It shows the river to be open in the lower valley.

In 1977, break-up progressed in almost the same way as in 1976 (Table 1), and the NOAA imagery was very useful in documenting it. Fig. 6 shows the break-up of ice in the lower valley of the Mackenzie River. Due to malfunctioning of Landsat-1, imagery from it was not available during the break-up period, and Landsat-2 coverage did not correspond closely with the progress of break-up.

Forecasting of break-up appears feasible, subject to further study. Once it starts east of Fort Simpson, the average rates at which it occurs along different sections of the Mackenzie River can be calculated. These rates taken in conjunction with meteorological data could be used to forecast break-up dates along the entire river at least two weeks in advance.

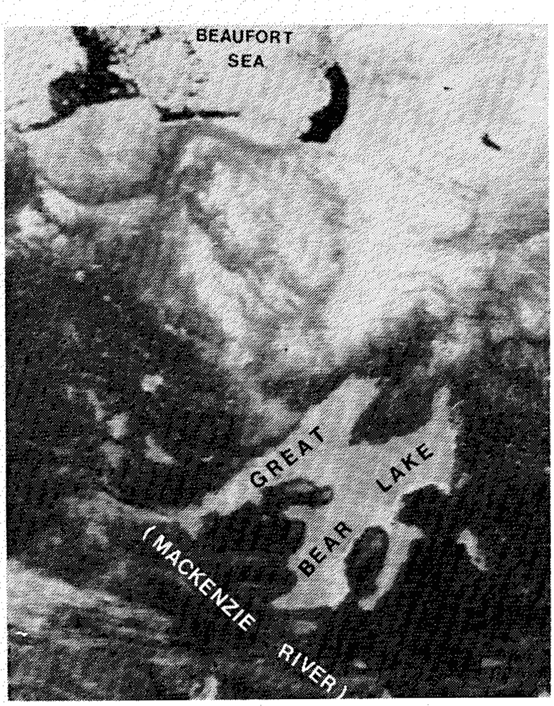

FIG. 6. NOAA image, 31 May 1977. It shows the lower valley to be ice free.

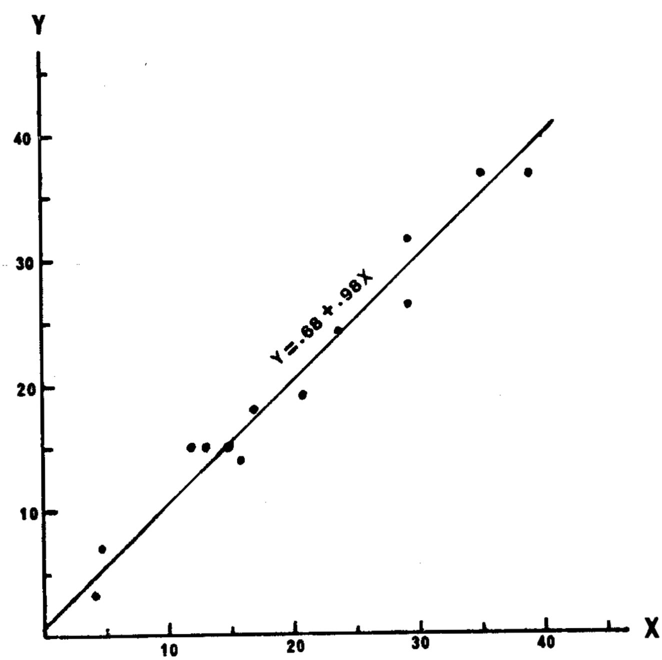

FIG. 7. Graph of the correlation between field-observed dates (X-axis) and break-up dates derived from satellite imagery (Y-axis), all numbered from 1 May.

In Fig. 7, the dates of break-up of river ice, as observed at the six ground stations, are shown plotted against the corresponding dates derived from the satellite imagery. The very high degree of correlation between the two sets of dates is indicated by the slope of the graph (0.98). The small differences between corresponding pairs of dates might be related to: the limited usefulness of field-observed data as a source of information concerning break-up; the limited coverage and timing of Landsat imagery; the presence of cloud cover; and the factor of human error in the interpretation of the photographs.

The difficulty with point-source (field-data) information is that the river may melt at a particular reporting station while it is still frozen upstream and downstream (Fig. 3). The satellite imagery gives synoptic information concerning break-up which is useful for river navigation.

Landsat-1 and Landsat-2 imagery has certain inherent limitations which include the satellite's nine-day period and the limited geographic area covered by its image frames. The latter makes mapping of snow and the study of break-up on rivers difficult in basins larger than 34,000 square kilometres in extent (Wiesnet and McGinnis 1973). For a basin like the Mackenzie (1.8 million square kilometres), several satellite passes would have to be put together for complete geographic coverage to be assumed. The progress of snowmelt and break-up on rivers is so rapid that the nine-day period and the limited coverage provided together preclude the use of Landsat imagery as the only source of information for operational use in the study of ice break-up. The NOAA satellite, on the other hand, has a one-day period, and furthermore, due to its very small scale, one image frame can cover the entire Mackenzie Basin (Fig. 2). However, such small-scale imagery has two major limitations: low resolution and geometric distortion.

Cloud cover may obscure both types of imagery and preclude observations of the rivers. Under some circumstances, clouds can also be mistaken for snow cover. Since cloud is not static, the examination of NOAA imagery on successive days helps to discriminate between snow and cloud. Manual interpretation of photographs may cause some error in the location of snow-line and break-up limits. However, experience should overcome this difficulty.

CONCLUSIONS

Satellite imagery provides a synoptic picture of break-up of river ice which it is not possible to obtain from point observations on the ground. NOAA-VHRR imagery has demonstrated its usefulness for daily synoptic, real-time (i.e. non-recorded) information on ice break-up. Landsat-MSS imagery is also useful because of its high resolution. Although neither NOAA nor Landsat satellites could be used alone to perform all necessary mapping of snowmelt and river break-up, both in combination provided comprehensive information concerning break-up. They could therefore be used to study the patterns of break-up in rivers where little or no hydrometeorological data are presently being collected. In addition, the use of satellite imagery would aid in overcoming the high cost of acquiring hydrological data as a result of the physical limitations of the Arctic environment.

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