80-10237

TM-80686



NASA

Technical Memorandum 80686

# Use of Landsat Data for River and Lake Ice Engineering Studies

N80-29806

(E80-10237) USE OF LANDSAT DATA FOR RIVER AND LAKE ICE ENGINEERING STUDIES (NASA) 14 p HC A02/MF A01 CSCL 08L

Unclas G3/43 00237

Dorothy K. Hall

APRIL 1980

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

GODDARD SPACE FLIGHT CENTER

REQUEST FOR APPROVAL FOR PUBLICATION AND RELEASE

*(See Reverse for Detailed Instructions) (Refer to GMI 2220.5, Approval and Special Requirements for GSFC Publications)*

**1. TITLE**
Use of Landsat Data for River and Lake Ice Engineering Studies

**2. DOCUMENT NUMBER**
TM 80686

Typed name and signature of Author(s)
Dorothy K. Hall    Dorothy K. Hall

**3. APPROVAL REQUESTED FOR:**
- ☐ Presentation
- ☒ Journal Publication
- ☐ Formal NASA Report
- ☐ X-Document (Working Paper)
- ☒ Preprint (TM)
- ☐ Thesis (TM)

**NOTE: COMPLETE FOR PRESENTATIONS, JOURNAL PUBLICATION AND PREPRINTS**

4. Name of organization or professional meeting, location and date held

5. Name of journal, proceedings, etc.
River and Lake Ice Engineering

**6. PUBLICATION CONTENT CONSIDERATIONS:**

| YES | NO | |
|---|---|---|
| ☐ | ☒ | Contains Classified Material |
| ☒ | ☐ | Uses International System of Units (SI) |
| ☐ | ☒ | Describes Potentially Patentable Subject Matter |

* Forward to Patent Counsel, Code 204
(i.e., A new and useful process, product, mechanical and electrical arrangement of parts, or composition or matter.)

6a. Typed name and signature of reviewer in Office of Patent Counsel

7. This paper has been prepared keeping specifically in mind trade secrets or suggestions of outside individuals or concerns which have been communicated to the Center in confidence, and does not violate any such disclosures, and has been examined to see that all participating groups have been given proper credit.

Dorothy K. Hall
Dorothy K. Hall    Primary Author

**APPROVALS AND APPROVAL AUTHORITY** (See instructions on the reverse of this form)

| | | Comments | Code | Date |
|---|---|---|---|---|
| 8a. Typed name and signature of Branch Head<br>Albert Rango<br>Albert Rango | ☒ Approve<br>☐ Disapprove | | 924 | 4/11/80 |
| 8b. Typed name and signature of Division Chief<br>Vincent V. Salomonson<br>Vincent V. Salomonson | ☒ Approve<br>☐ Disapprove | | 920 | 4/12/80 |
| FOR EARLY DOMESTIC DISSEMINATION. The Division Chief MUST Also Indicate FEDD Applicability. | ☐ YES<br>☒ NO | This paper presents information having potential commercial application as outlined in GMI 2210.1. | | |
| 8c. Typed name and signature of Director of<br>L. H. Meredith<br>L. H. Meredith | ☒ Approve<br>☐ Disapprove | | 900 | 4/22/80 |
| 8d. Typed name and signature Office of the Director | ☐ Approve<br>☐ Disapprove | | | |

**DOCUMENT RELEASE INSTRUCTIONS**

9. CONTRACTOR REPORTS – HIGH NUMBERED
1. ☐ Announce in STAR (no limitations on availability)
2. ☐ Announce in LSTAR (distribution limited as indicated)
   - a. ☐ U.S. Government Agencies and Contractors Only
   - b. ☐ U.S. Government Agencies Only
   - c. ☐ NASA and NASA contractors Only
3. ☒ Release by Originating Office Only

GSFC 25-42(10/77)

1–PRINTING MANAGEMENT OFFICE

Use of Landsat Data for River and Lake Ice Engineering Studies

Dorothy ‹ Hall
NASA/Goddard Spa‹ . Flight Center

## Introduction

Problems associated with engineering and transportation in lakes and rivers prone to severe ice conditions can be alleviated, and in some cases avoided with proper planning. Landsat data have been shown to be useful in such planning efforts for control of ice jams and aufeis, for analysis of flooding and breakup patterns, for assessing ice extent in rivers and lakes for aiding transportation, and for locating winter water supplies in deep lakes which do not freeze to their beds in Arctic Alaska. In addition, continuous environmental data can be obtained and recorded remotely, in data-sparse areas, by placement of a Data Collection Platform (DCP) which transmits pertinent information via Landsat to the user. Landsat data can also be useful for determining the location of shallow lakes which may be suitable for landing aircraft on the Arctic Slope of Alaska. Lead patterns in the Great Lakes can be studied as an aid to shipping and navigation.

The Landsat satellites have been operating since July 23, 1972 when Landsat-1 (formerly called ERTS-1) was launched. Landsats-2 and -3 were launched on January 22, 1975 and March 5, 1978 respectively and were equipped with remote sensing capabilities similar to those on Landsat-1. The Multispectral Scanner Subsystem (MSS) on-board the Landsat satellites is a four-channel system which senses radiation in the visible and near-infrared portions of the spectrum. Bands 4 (0.5 - 0.6 μm) and 5 (0.6 - 0.7 μm) are the visible bands, and bands 6 (0.7 - 0.8 μm) and 7 (0.8 - 1.1 μm) are the near-infrared bands. The MSS provides imagery with a spatial resolution of 80 meters. Return Beam Vidicon (RBV) cameras, also part of the Landsat payload, provide better resolution than the MSS sensors (24 - 79 meters) but RBV imagery is not as available as is MSS imagery. The RBV cameras operate in the visible part of the spectrum between 0.48 and 0.83 mm (General Electric, 1978).

Landsat data can be especially useful in high latitudes for river and ice studies because the Landsat orbit creates sidelap of images. Sidelap can provide sequential data of the same features on more than one day in the orbital cycle.

In addition to the imaging capabilities, Landsat can be used as part of a relay system which collects data from widely distributed, often remote places through a ground-based Data Collection Platform (DCP) from which messages are transmitted via Landsat to a central processing station and subsequently disseminated to the user.

Each Landsat scene derived from the MSS covers an area which is 185 kilometers on a side, or $\sim$ 16,000 $km^2$ in area. Analysis of a mosaic of several Landsat images provides an overview which can be useful in analysis of regional patterns. The history of ice patterns (for example: ice jam occurrence, aufeis distribution and ice extent and breakup) can also be studied back to the launch of Landsat-1.

In order to maximize the utility of remotely-sensed data for river and lake ice studies, Landsat data should be analyzed in concert with data from sensors operating in other parts of the spectrum. Side Looking Airborne Radar (SLAR) and Synthetic Aperture Radar (SAR) data prove to be compatable with Landsat data for many such studies (Foster and Hall, 1980).

## River Ice Engineering and Transportation

During the breakup period in the Arctic and subarctic, ice jams may form when river waters rise beneath the ice cover eventually breaking up the river ice into large floes. As these floes drift downstream, they may become grounded on gravel bars or meanders of the main river channel thus forming an ice jam or a blockage to the continued flow of water (Miller and Osterkamp, 1978). Flooding ensues upstream from the ice jam and to the sides of the river possibly endangering property, and impeding transportation. Erosion and deposition of sediments may result causing dredging to be necessary (Degtyarev et al, 1975). In some parts of Alaska, ice jams block the flow of rivers for up to a week each May (Miller and Osterkamp, 1978).

Several techniques have been employed to alleviate (by blasting) and prevent (by dusting) the effects of ice jams. The blasting technique is self explanatory and is performed after the ice jam has occurred. The dusting technique is a preventative measure in which sand or dust is spread on river ice and snow prior to breakup (in April) in order to lower the albedo of the ice. Portions of the river channel downstream from the ice jam location are dusted in order to accelerate melting in specific locations prone to ice jams. Ice floes can then move freely through a channel opened by this technique (Miller and Osterkamp, 1978).

The effectiveness of the dusting technique is dependent upon precise pinpointing of the main river channel; Landsat imagery acquired in the fall can be useful for locating the main river channel. In the Arctic, river channels migrate and may not be in the same location from year to year. Miller and Osterkamp (1978) found that Landsat band 4 imagery was useful for precisely locating the main channel, and probable sites for ice jams on the Yukon River (Figure 1). Using enlargements of Landsat imagery, they were able to specify target areas for dusting. They concluded that Landsat data were potentially useful for ice jam prevention in Alaskan rivers and that conventional aerial photography was too expensive to routinely monitor the thousands of miles of Alaskan rivers that are subject to ice jam formation.

Stream aufeis can cause damage to engineering projects in Arctic and subarctic regions. Aufeis, also known as icings and naleds, is formed by ground or river water which continues to flow after the initial river freeze-up. As the impermeable ice cover and the impermeable permafrost (or seasonally frozen ground) coalesce in a river channel, hydrostatic pressure builds up as intrachannel and subchannel water continues to flow (Figure 2). Cracks develop in weak points in the ice cover and at the sides of the ice cover and the water flows upward under pressure. This process continues in successive overflows until the source of groundwater is exhausted (Carey, 1973).

Aufeis can be inadvertently be created by man's interrupting the natural flow of groundwater during construction (Grey and MacKay, 1977). Waters which form large aufeis fields in Siberia and Alaska emanate from deep groundwater which are controlled by tectonic fracture patterns in the area (Osokin, 1978 and Hall, 1980a). Aufeis then forms at outflows from springs (Childers et al, 1977). Knowledge of the locations of known aufeis fields in Arctic and subarctic rivers is useful for delineating sources of freshwater (Carey, 1973) and for avoiding the placement of structures (pipelines, bridges, etc.) near aufeis-prone areas because of the great pressures which can be exerted upon such structures.

Large aufeis fields can be located and measured using Landsat imagery. Holmgren and Benson (1974) found MSS bands 6 and 7 to be the most useful for locating aufeis prior to snowmelt. The absorption coefficient for ice is higher in the near-infrared than it is in the visible range of the spectrum, thus aufeis appears darker than the snowcovered tundra in band 6 and 7 imagery. Bands 4 and 5 show the best contrast between the highly reflective aufeis, and the surrounding terrain on spring and summer Landsat imagery after the snow has melted (Holmgren and Benson, 1974 and Harden et al, 1977). The visible bands were found to be best for measuring aufeis extent after snowmelt (Holmgren and Benson, 1974 and Hall, 1980b).

Band 5 Landsat imagery was used to locate, measure and analyze interannual variations in the extent of aufeis by Hall (1980b) for the years 1973 through 1979 for seven aufeis fields in the eastern Arctic Coastal Plain of Alaska. The aufeis under study was found to vary considerably among the years studied. Because of this inherent variability of aufeis, one cannot use one year of information to determine aufeis extent when considering construction in areas prone to aufeis development. Landsat data provide an historical record of aufeis extent variations back to July of 1972.

The incidence of flooding due to aufeis in river channels was discussed by Stringer et al (1976). Flooding can result if aufeis fills a stream channel causing the streamflow to be diverted onto the floodplain. Flood waters will freeze in the winter, but will inundate surrounding areas with water from streamflow in the spring and summer months. South of Delta Junction, Alaska, Stringer et al (1976) found a large dark area in band 6 and 7 Landsat imagery. This was found to be flooded. Although the flooding had long created problems in the town of Delta Junction, Landsat data enabled the source and extent of the flooding to be mapped using spring 1974 imagery. Stringer et al (1976) found that the best approach for identifying the flooded areas was to simultaneously project bands 5 and 7 onto a viewing screen, and reproduce the product for use as a map. Flooding resulting from aufeis is a major cause for highway maintenance often resulting in washouts and should be considered in the design of any construction project in many parts of Alaska (Stringer et al, 1976).

Holmgren et al (1975) used Landsat imagery to analyze the snow and ice breakup patterns on the Arctic Slope of Alaska. They studied imagery before. during and after breakup, in March, May and June of 1973. The main rivers stand out clearly in all of the images probably due to a combination of the presence of stream aufeis, riparian vegetation and topographic effects. The rivers were found to be far more advanced in breakup than the surrounding tundra and acted as nucleii of ablation from which melting occurred outward along the channels. This lowers the local albedo and energy budget. Additionally, Holmgren et al (1975) found that there was a time-lag in the breakup of rivers in which the source regions were restricted to the foothills (the Kuparuk and Putuligayuk Rivers). Rivers originating in the Brooks Range, such as the Sagavanirktok River, experienced earlier breakup.

Innundation of coastal sea ice by rivers in northern Alaska has been studied by Barnes and Reimnitz (1976) using Landsat imagery. Rivers flood prior to complete ice breakup, and prior to the retreat of coastal sea ice. It is important to be aware of the progression the coastal sea ice flooding for the safe utilization of installations and transportation near deltas (Barnes and Reimnitz, 1976).

Barnes and Reimnitz (1976) studied a four-day sequence of Landsat images showing river flooding of sea ice from the Sagavanirktok River near Prudhoe Bay, Alaska. They monitored the development of flooding by noting the expansion of dark areas of the Sagavanirktok River delta. They measured the inundated area from Landsat imagery and showed that it increased from ~ 18 $km^2$ to 43 $km^2$ between May 23 and 27, 1973. Through their examination of Landsat imagery, it was found that the rivers of the Alaskan Arctic Slope overflow in sequence from southeast to northwest in response to variations in solar insolation at different latitudes.

Potential transportation problems can be monitored using Landsat data. For example, Quinn et al (1978) and Foster et al (1978) used Landsat imagery to show the ice extent on Lake Michigan and the Chesapeake Bay respectively. Foster et al (1978) demonstrated that different types of ice could be identified on rivers which flow into the Chesapeake Bay. Ice types could then be classified based on spectral signatures on an image analysis computer. Based on the spectral signatures, visual analysis of selected imagery and in-situ measurements, Foster et al (1978) inferred ice thickness on the Chesapeake Bay and its tributaries. They noted that severe ice conditions during 1977 prevented an oil barge from carrying fuel oil on its usual route on the Wicomoco River to Salisbury, Maryland during the severe ice conditions experienced in the winter of 1977.

Lake Ice Engineering and Transportation

Accurate knowledge of ice conditions and extent on the Great Lakes is of considerable economic importance. Wiesnet (1974) used Landsat imagery to analyze the ice coverage of Lake Erie. He observed the formation of cracks in the ice between two Landsat images taken on two different days (February 18 and 19, 1973). He further utilized Landsat band 7 imagery to observed breakup of the ice near Cleveland, Ohio by moderate (10 knot) winds.

Another important use of Landsat imagery in lake ice studies is the ability to infer the ice thickness of thaw lakes on the Arctic Slope of Alaska for transportation, engineering and water supply uses. Sellman et al (1975a) have found that sequential ice cover changes as observed on Landsat imagery, can be indicative of lake depth. This is because deep lakes retain their ice covers longer than shallow lakes since the amount of ice to melt is greater on deeper lakes. Furthermore, it is known that lakes deeper than about 2 meters on the Arctic Slope do not freeze to their beds during the winters. These 'deep' lakes are important for biological resources (overwintering fish) and water supplies (Sellman et al, 1975a and 1975b). Used in conjunction with appropriately-timed SLAR imagery, specific lakes can be qualitatively categorized according to depth (Sellman et al, 1975b).

Knowledge of the locations of shallow lakes on the Arctic Slope can also be important for transportation (O'Lone, 1975). Large-scale air support is required during oil exploration, construction and off-shore drilling operations. The possibility of landing wide-body cargo aircraft on lakes which are frozen to their beds has been discussed (O'Lone, 1975). Only shallow lakes whcih are frozen to their beds would be able to support such landings. Certain 'runways' on shallow lakes may be usable from November through April (O'Lone, 1975). Candidate lakes for such operations may be selected using both Landsat and radar imagery.

## Conclusion

Landsat data have proven to be highly valuable for river and lake ice studies using the MSS imagery and digital data. Landsat imagery can provide a regional overview of an area, or it can be used to pinpoint specific sites for transportation and engineering operations. River and lake ice formation and breakup patterns can be analyzed back to the launch of Landsat-1 in 1972 providing an historical perspective. The Landsat series continues to provide information on interannual changes in river and lake ice, and also provides a record of natural events that may otherwise have gone unrecorded.

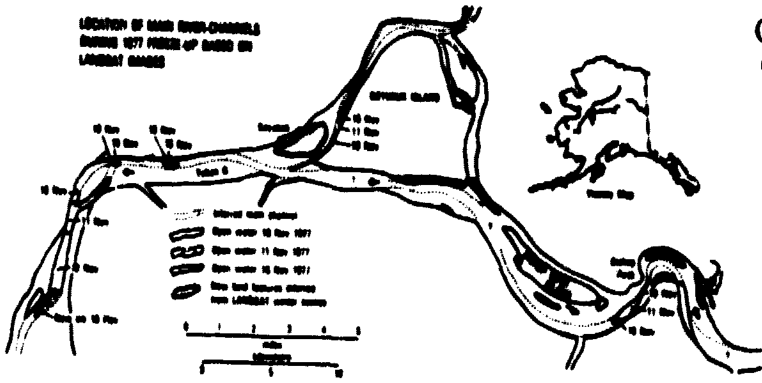

Figure 1. River Channel Locations Determined from Landsat imagery for Ice Jam Avoidance (from Miller and Osterkamp, 1978).

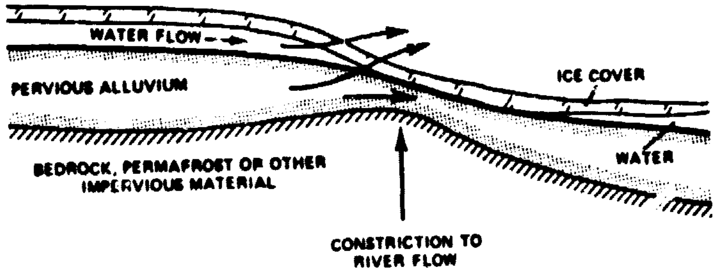


Figure 2. Formation of Stream Aufeis (After Carey, 1973).

References:

Barnes, P. W. and E. Reimnitz, 1976: Flooding of Sea Ice by the Rivers of Northern Alaska. ERTS-1 A New Window to our Planet, R. S. Williams and W. D. Carter (ed.), USGS Prof. Paper 929, pp. 356-359.

Carey, K. L., 1973: Icings Developed from Surface Water and Ground Water. CRREL Monograph 111 - D3, Hanover, NH, 67 pp.

Childers, J. M., C. E. Sloan, J. P. Meckel and J. W. Nauman, 1977: Hydrologic Reconnaissance of the Eastern North Slope, Alaska, 1975. U.S.G.S. Open File Report 77-492, 65 pp.

Degtyarev, V. V., I P. Butyagin and Morgunov, V. K., 1975: Investigations of Ice Jams on the Siberian Rivers and Measures Taken to Prevent them. Third International Symposium on Ice Problems, G. E. Frankenstein (ed.), Hanover, NH, pp. 223-232.

Foster, J. L., D. Schultz and W. C. Dallam, 1978: Ice Conditions on the Chesapeake Bay as Observed from Landsat During the Winter of 1977. Proceedings of the 1978 Eastern Snow Conference, Feb. 2-3, Hanover, NH, pp. 89-104.

Foster, J. L. and D. K. Hall, 1980: Multisensor Analysis of Hydrologic Features in the Wind River Range, Wyoming with Emphasis on the Seasat SAR. NASA TM 80582, 23 pp.

General Electric, 1978: Landsat 3 Reference Manual. Valley Forge, PA.

Grey, B. J. and D. K. MacKay, 1977: Aufeis (Overflow Ice) in Rivers. Inland Waters Directorate, Environment, Canada, 31 pp.

Hall, D. K., 1980a: Mineral Precipitation in North Slope Aufeis Fields. Arctic V. 33.

Hall, D. K., 1980b: Analysis of the Factors Influencing the Occurrence of Aufeis on the Arctic Slope of Alaska. Unpublished Ph.D. Dissertation, University of Maryland.

Harden, D., P. Barnes and E. Reimnitz, 1977: Distribution and Character of Naleds in Northeastern Alaska. Arctic, V. 30, pp. 28-40.

Holmgren, B. and C. S. Benson, 1974: Aufeis as Observed by ERTS. Contract report to National Aeronautics and Space Administration by University of Alaska Geophysical Institute, pp. 69-82.

Holmgren, B., C. Benson and G. Weller, 1975: A Study of Breakup on the Arctic Slope of Alaska by Ground, Air and Satellite Observations. Climate of the Arctic, Weller, G. and S. A. Bowling (ed.), University of Alaska, Fairbanks, AK, pp. 358-366.

Miller, J. M. and T. E. Osterkamp, 1978: The Use of Landsat Data to Minimize Flooding Risks Caused by Ice Jams in Alaskan Rivers. Proc. of the Twelfth International Symposium on Remote Sensing of Environment V. III, ERIM, pp. 2255-2266.

O'Lone, R. G., 1975: Alaskan Air Support Facing Challenges. Aviation Week and Space Technology, V. 103, No. 103, pp. 14-17.

Osokin, I. M., 1978: Zonation and Regime of Naleds in Trans-Baikal Region. U.S.S.R. Contribution to Second International Conference on Permafrost, July 13-28, 1973, NAS, Wash., D.C., pp. 391-395.

Quinn, F. H., R. A. Assel, D. E. Boyce, G. A. Leshkevich, C. R. Snider and D. Wiesnet, 1978: Summary of Great Lakes Weather and Ice Conditions, Winter 1976-77. NOAA Tech. Memo. ERL/GLERL-20, 141 pp.

Sellman, P. V., J. Brown, R. I. Lewellen, H. McKim and C. Merry, 1975a: The Classification and Geomorphic Implications of Thaw Lakes on the Arctic Coastal Plain, Alaska. CRREL RR 344, 21 pp.

Sellman, P. V., W. F. Weeks and W. J. Campbell, 1975b: Use of Side-Looking Airborne Radar to Determine Lake Depth on the Alaskan North Slope. CRREL SR 230, 6 pp.

Stringer, W. J., T. H. George and R. M. Bell, 1976: Identification of Flood Hazard Resulting from Aufeis Formation in an Interior Alaskan Stream. U.S. Dept. of Agriculture, Portland, OR, 12 pp.

Wiesnet, D. R., 1974: The Role of Satellites in Snow and Ice Measurements. International Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources, compiled by Santeford, H. S. and J. L. Smith, NAS, pp. 447-456.

## BIBLIOGRAPHIC DATA SHEET

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| TM 80686 | | |

**4. Title and Subtitle**
Use of Landsat Data for River and Lake Ice Engineering Studies

**5. Report Date**
April 1980

**6. Performing Organization Code**


**7. Author(s).**
Dorothy K. Hall


**8. Performing Organization Report No.**

**9. Performing Organization Name and Address**

**10. Work Unit No.**

**11. Contract or Grant No.**

**12. Sponsoring Agency Name and Address**

**13. Type of Report and Period Covered**

**14. Sponsoring Agency Code**

**15. Supplementary Notes**

To appear in River and Lake Ice Engineering, a book to be published jointly by the U.S. Army Cold Regions Research and Engineering Lab and the IAHR Committee on Ice Problems.

**16. Abstract.**


A review of literature discussing the utility of Landsat data for river and lake ice engineering studies is presented. Ice jams, aufeis, river ice breakup and lake ice depths are discussed with emphasis on Arctic Alaska.


**17. Key Words (Selected by Author(s))**

Landsat
Ice Engineering
River and Lake Ice
Ice Jams
Aufeis

**18. Distribution Statement**

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| | | | |

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

GSFC 25-44 (10/77)