WESTERN REGION TECHNICAL ATTACHMENT
NO. 01-11
September 4, 2001

USING RADARSAT TO MONITOR AND FORECAST RIVER ICE MOVEMENT IN NORTHEAST MONTANA

Tom Wright and Andrew Pohl
Weather Forecast Office, Glasgow, MT

[Note: Because of the large number of figures, only the text will be published in hard copy. The figures can be accessed on the Web version at http://www.wrh.noaa.gov under Technical Attachments.

1. Introduction

The importance of being able to detect and monitor floods of all kinds in a timely manner cannot be understated. Ice-jam flooding, in particular, is very prevalent in Montana. There have been 1,046 recorded ice jam floods in Montana since 1894 (Kolman 2000). March is by far the most ice jam-prone month of the year in Montana with nearly half of all ice jams occurring in that month.

Ice-jam flooding is of particular concern in northeast Montana because most spring floods in the region are ice-jam related. Most of the water that flows east of the continental divide in Montana flows through the Glasgow Hydrological Services Area (HSA). During the spring, the higher elevations of eastern Montana tend to warm up more quickly than the lower elevations. This causes upstream water to back up behind the still frozen portions of rivers further downstream, resulting in ice jam flooding, especially along the Yellowstone River, which flows to the northeast.

Ice jams on the Yellowstone River, and their related damage, have been well documented over the last 100 years. This is probably because most of the population in eastern Montana lives along its banks. The WFO Glasgow records show there have been 22 ice-jam related floods since 1900 and 13 ice jam flood fatalities in Glendive, Montana. But ice-jam flooding is certainly not confined to the Yellowstone River. Virtually every community along the banks of any major river in eastern Montana is susceptible to ice jam related flooding.

The methods available for monitoring river ice over sparsely populated sections of northeast Montana are limited. The prevalence of low cloud during the late winter and spring months makes the use of conventional visible satellite imagery ineffective in monitoring river ice. Unlike Alaska, the state of Montana does not perform aerial reconnaissance for river ice flooding. Automated river observations are sparsely distributed and have proven inadequate in monitoring the thousands of miles of rivers and streams in the Glasgow HSA. Although we do receive river reports from such sources as County Disaster and Emergency Service (DES) Coordinators, they cannot always provide the whole picture.

This technical attachment explores the use of Canadian RADARSAT data to monitor and forecast river ice movement. In section 2, background information on RADARSAT will be presented. In section 3, we will demonstrate how we used the RADARSAT data. In section 4, examples of how RADARSAT data were used during March 2001 are shown. Section 5 has a discussion of the performance of the RADARSAT data.

2. RADARSAT Background

RADARSAT (RSI 2001) is a synthetic aperture C-band radar [SAR, (Lunsford 1998)] riding on a sun-synchronous earth orbiting satellite. It was developed by a Canadian company, RADARSAT International (RSI), during the oil crisis of the 1970's to monitor ice in the oil shipping lanes of the Beaufort Sea. The current satellite, RADARSAT 1, was launched in November 1995, with RADARSAT 2 scheduled to be launched in late 2002. SAR data are particularly useful in hydrological applications due to microwave radiation's sensitivity to the presence of water. Because of the characteristics of SAR's, they are able to penetrate most fog and low cloud and differentiate between liquid water and ice on the earth's surface.

The orbit of RADARSAT 1 is such that northern latitudes are revisited more often than southern latitudes. The satellite revisits the area between 40° and 50° north latitude (Glasgow's HSA) every 1.5 to 3 days. The SAR has a number of beam modes ranging from high-to-low resolution. The data used by WFO Glasgow were collected in the standard beam mode which had a resolution of 25mX28m, swath width of 100km, incidence angle of 20-49°, and a pixel size of 12.5m. Data of this quality are only available every 3 days. Lower quality data are available more frequently.

3. Methods

Routine real time access to current RADARSAT imagery for single WFO operations is not practical. WFO Glasgow ordered a graduated data downloading schedule for March 2001. By the latter portion of March, data were available every 72 hours (3 days). This schedule was expected to provide a good testing sample since, historically, a large portion of the desired study events occurred in the latter part of March. The data were available about 3 hours after the satellite pass. RSI passed the raw images, each about 150 megabytes in size, to National Environmental Satellite and Data Information Service (NESDIS). WFO Glasgow then downloaded the images from NESDIS.

Once downloaded by WFO Glasgow, the data were processed with Adobe Photoshop 6 (Adobe 2000). Images were cropped and the brightness and contrast were calibrated to accentuate those areas that were of interest. Efforts were made to keep the calibration consistent from image to image to aid in data analysis and comparison.

Once processing was complete, the image was analyzed for potential ice jam formation on the Yellowstone River. Since this technology had not been used by WFO Glasgow before, analysis proceeded largely by trial and error at first. We compared known ice conditions with those seen on RADARSAT imagery. We quickly found that solid, unbroken ice appeared bright white. Open liquid water was very dark and decaying, or broken, ice and snow-covered ice appeared grayish and looked much like the surrounding land. Once we determined what ice jams should look like on RADARSAT imagery, we began to look at the entire Yellowstone River in the GGW HSA. When a suspect area was identified, every effort was made to collect conventional data to verify or refute what was indicated by RADARSAT imagery.

Figure 1 shows the geographical area covered by the RADARSAT data used in this study. The long horizontal light blue lines show the footprint of the desired RADARSAT pass. The dark blue square is the area of data collection for our particular study. The disjointed red rectangle encloses the Yellowstone River Valley, which was the portion of the image we were interested in.

Figure 2 is an example of a full RADARSAT image. The Yellowstone River Valley is located within the dashed yellow lines. At this scale, the image is not useful for river ice monitoring. The other RADARSAT figures used in this Technical Attachment are magnified portions of a full size image. On all the images, north is generally toward the top and east is generally toward the right. The Yellowstone River flows toward the northeast (upper right) on all these images.

4. Examples/Case Studies From Spring 2001

March 2001 was warmer and much drier than normal across Northeast Montana. The average temperature for the month at Glasgow was 3.3 degrees above normal while only 0.06 inches of precipitation fell. There were very few days with dramatic temperature swings. The relative warmth of the month over the lower elevations and low river levels from lack of precipitation resulted in conditions that were not particularly conducive to ice jams.

Despite the lack of cooperation from the weather, we were able to observe a number of events that allowed us to test the use of RADARSAT data. We chose four events that illustrate how proper analysis of RADARSAT data can be used to monitor and forecast river ice movement more effectively and for a larger area than with conventional methods.

a. March 9 - Sidney, Montana

On March 9, the Richland County DES Coordinator provided us with some digital photographs taken of the Yellowstone River from the Highway 23 bridge in Sidney, Montana. (See Fig. 1 for location of Sidney.) The photos were taken both upstream and downstream (Figs. 3 and 4, respectively) and showed continuous ice in both directions. The DES Coordinator concluded that there was no open water on the Yellowstone River in the vicinity of Sidney.

In the past, that would have been the end of the story. However, the RADARSAT image from March 9 (Fig. 5), showed that the river was open both upstream and downstream of the Highway 23 bridge. Note how the river in the vicinity of the Highway 23 bridge is lighter and not easily distinguishable from the surrounding land when compared to the much darker downstream portions of the river. In order to verify our observations, the DES Coordinator drove into the hills southeast of Sidney. He confirmed our observation and was astonished to find that we could see from space what he could not see through normal observation from the ground.

b. March 16 - Confluence of the Yellowstone and Powder Rivers, Southeast Montana

The next example is from March 16, 2001. The image (Fig. 6) shows the confluence of the Powder river and the Yellowstone river between Terry and Kinsey, Montana (see Fig. 1). The RADARSAT image shows a small channel of open water, with ice on either side, flowing from the Powder river into the main channel of the Yellowstone. Two forecasters from the Glasgow office, including one of the authors, were at this location on this day and confirmed the presence of the small open channel of water.

c. March 20 - Glendive, Montana

On March 20, 2001, RADARSAT imagery (Fig. 7) indicated an ice field on the Yellowstone in Glendive (see Fig. 1) near the Bell Street bridge. The ice appeared to be decaying due to the grayish color of the river in the area. A comparison with subsequent photographs obtained from Dawson County DES (Figs. 8 and 9) confirmed that ice was beginning to decay.

Since there also appeared to be open water, both upstream (southwest) and downstream (northeast) of the decaying ice, we concluded that the ice was about to wash out of the Glendive Area. Observations from later that day confirmed that the ice did indeed wash out.

d. March 23 - Vicinity of Glendive, Montana

The RADARSAT image from March 23, 2001 (Fig. 10), provided us with the clearest pictures of ice and open water. A dam at Intake, Montana, north of Glendive, diverts water into a canal for irrigation purposes. Ice was clearly backed up behind this dam, with open water downstream of the dam.

Further upstream in Glendive, we were able to see an ice jam between the Business 94 bridge and the Interstate bridge (Fig. 11). An apparent widening of the channel was observed just upstream of the ice jam, indicating that a lot of water was being backed up there. A digital photograph (Fig. 12) taken from a camera at Glendive was used for comparison. The Business 94 bridge is in the foreground of Fig. 12 and the back edge of the ice jam just downstream can be seen in the figure; thus confirming the RADARSAT image.

5. Performance

In detecting ice jams and ice breakup, RADARSAT performed beyond expectation. Proper analyses of the data produced a far more complete picture of the river ice conditions in northeast Montana than could have been produced with any other observational aids, including direct observation. Ice jams and breakups were detected by analysis of RADARSAT data and, subsequently, visually verified by personnel on the ground. Slight changes in the apparent shape and width of rivers behind ice jams were detected during this study. These detections would have facilitated the issuance of advanced warnings to the public had this season's events warranted such actions.

6. Conclusion

RADARSAT Imagery proved itself to be an invaluable tool for monitoring and forecasting river ice movement in Northeast Montana. There is no doubt that the data could be used for similar purposes in other WFO's. To maximize its effectiveness in facilitating advanced warnings for ice jam-related flooding in the future, more frequent data are needed for a larger area.

7. Acknowledgments

The authors would like to the acknowledge the scientific contributions made to this project by Thomas L. Salem, Jr. (WFO GGW SOO) and James A. Rea (former WFO GGW MIC). In addition, William Pichel, NESDIS, made the study possible by providing RSI a realtime data storage site. We would also like to thank the DES Coordinators who, throughout the years, have helped the forecasters at Glasgow to monitor ice jams and flooding, especially Helen Conradsen and Butch Renders. Finally, we would like to thank the National Weather Service's Western Region Headquarters for providing the funding that made this study possible.

8. References

Adobe, 2000: Adobe Photoshop 6.0. Adobe Systems Incorporated

Kolman, J., 2000: "Of ice jams and raging rivers." *Billings Gazette*, 12 March 2000.

Lunsford, A.C., 1998: Use of SAR data at the Alaska River Forecast Center. *Proc. 14th International Symposium on Ice*, Potsdam, NY, A. A. Balkema, 25-29.

RSI, cited 2001: RADARSAT-1 - Overview. [Available on-line from http://www.rsi.ca/classroom/cl-rsat.htm.]

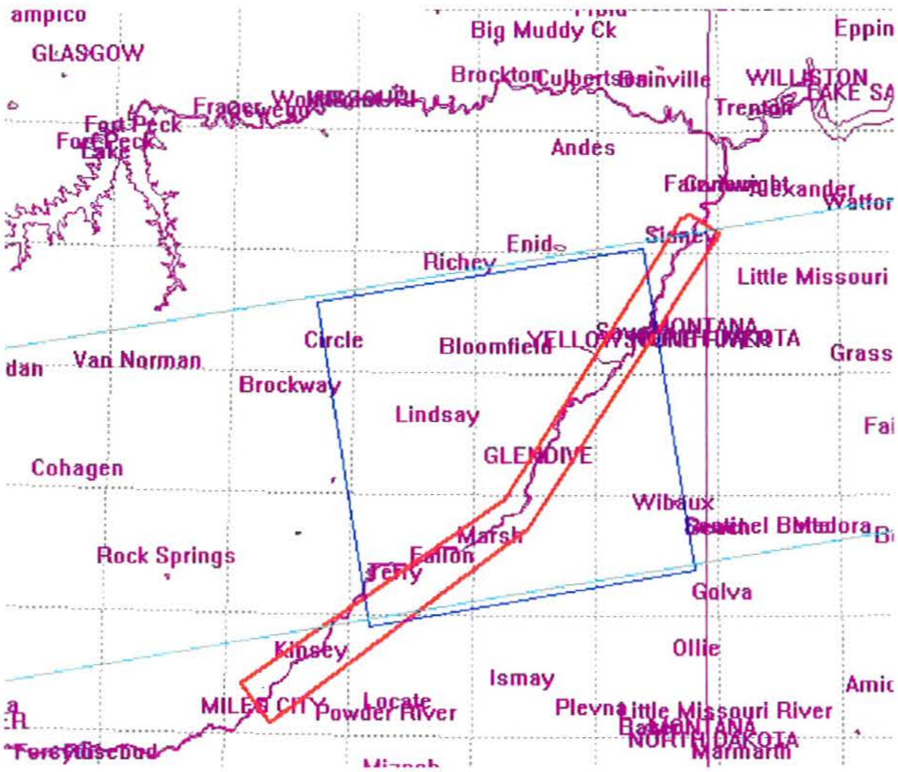

Figure 1. Portion of Northeast Montana where RADARSAT data were collected. The light blue line is the RADARSAT pass for March 16, 2001. The dark blue square is the area of the data received from RADARSAT for March 16. The Yellowstone River Valley is highlighted by the red "rectangle."

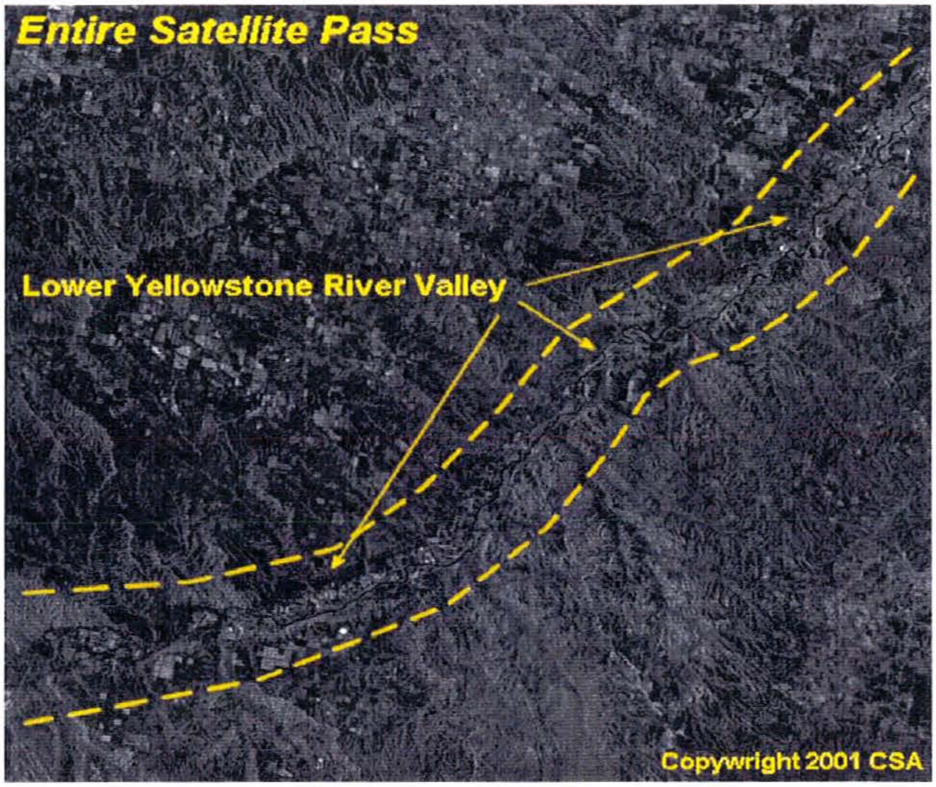

Figure 2. A full RADARSAT image from March 16, 2001. The Yellowstone River Valley has been highlighted.

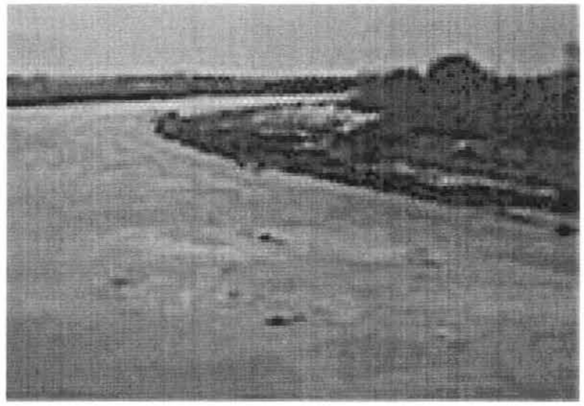

Figure 3. Photograph from March 9, 2001, of the Yellowstone River looking upstream of the Highway 23 bridge, near Sidney.

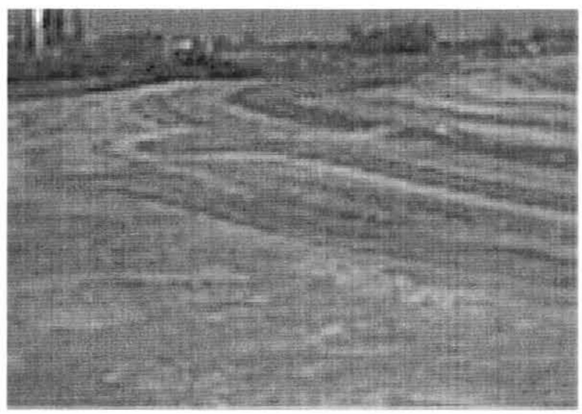

Figure 4. Photograph from March 9, 2001, of the Yellowstone River looking downstream of the Highway 23 bridge, near Sidney.

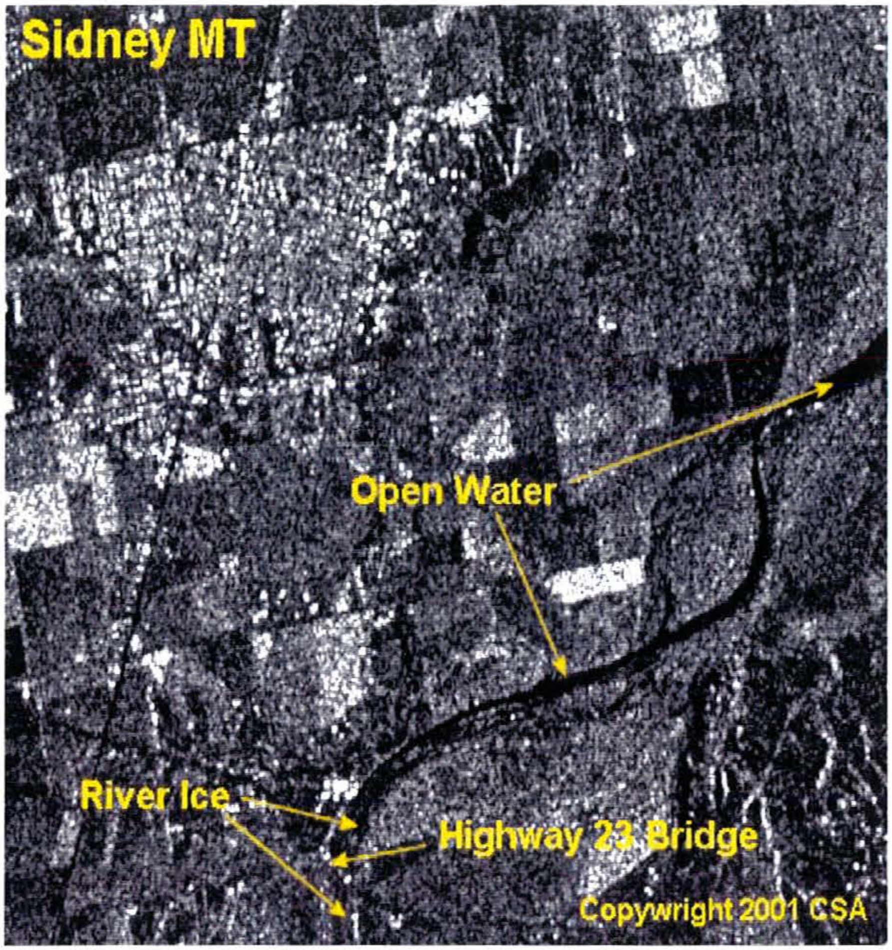

Figure 5. RADARSAT image from March 9, 2001, at 5:05 a.m. MST. The image has been cropped, highlighted, and magnified in the vicinity of Sidney. Note the open water north of the Highway 23 bridge, yet near the Highway 23 bridge there is still ice as seen in Figures. 3 and 4.

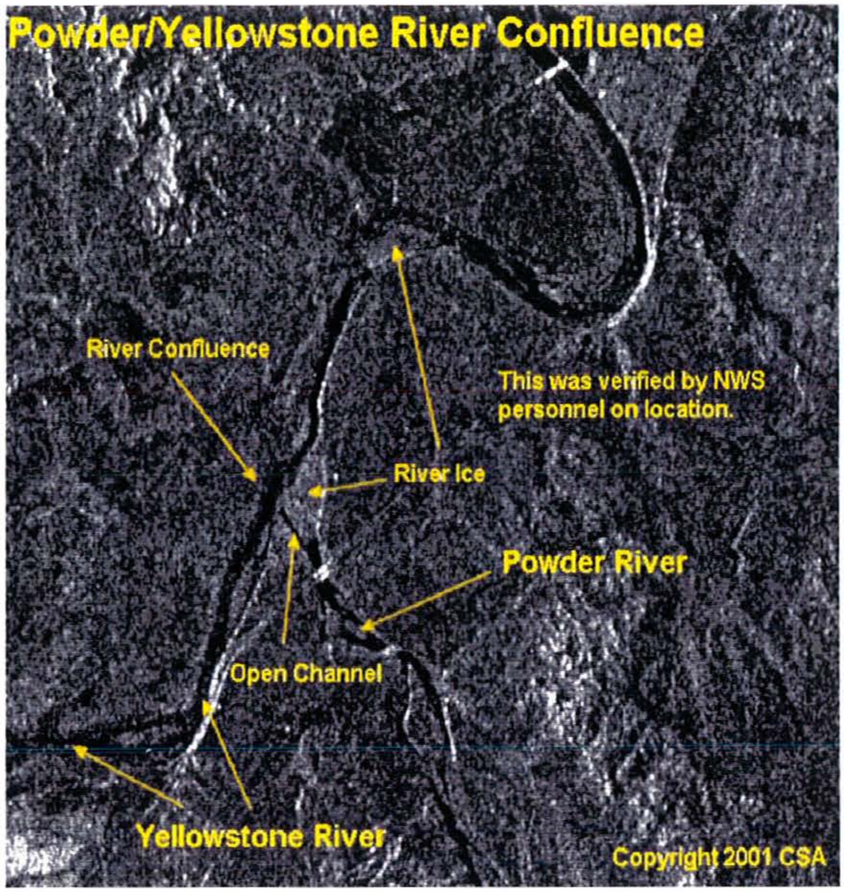

Figure 6. RADARSAT image from March 16 at 5:52 p.m. MST. The image has been cropped, magnified, and highlighted near the confluence of the Yellowstone and Powder Rivers, in southeast Montana. Note, the difference in shading of open water and river ice.

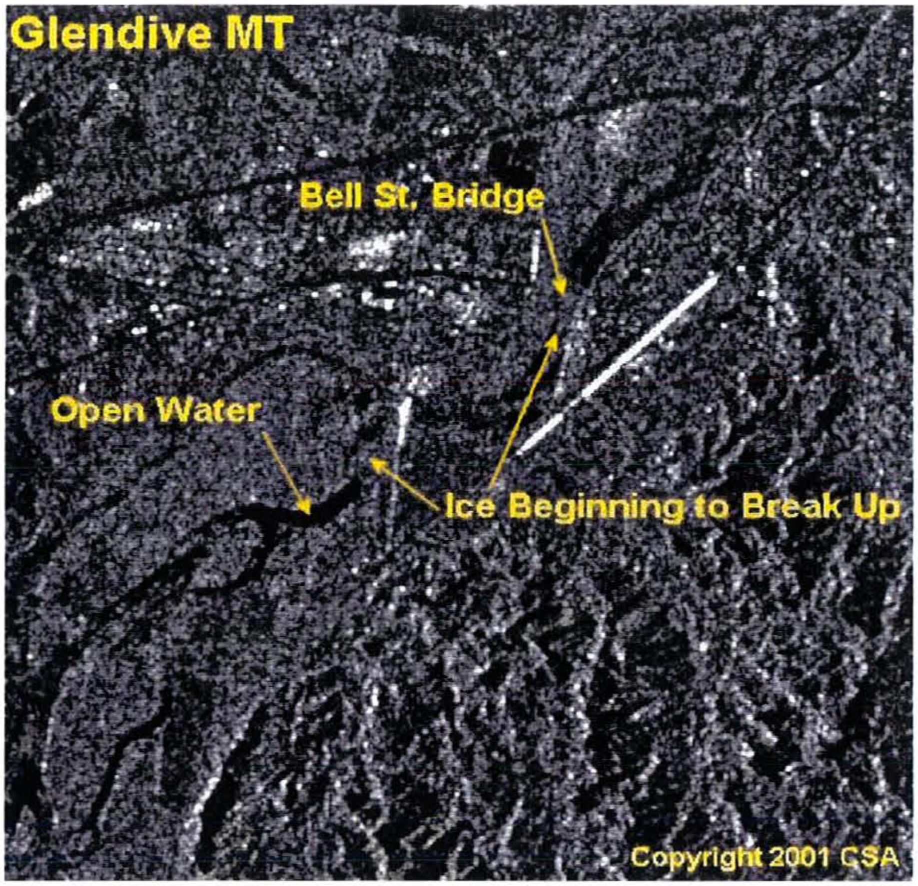

Figure 7. RADARSAT image from March 20 at 5:35 p.m. MST. The image has been cropped, magnified, and highlighted near Glendive. Note, the different shading of ice near the Bell St. bridge.

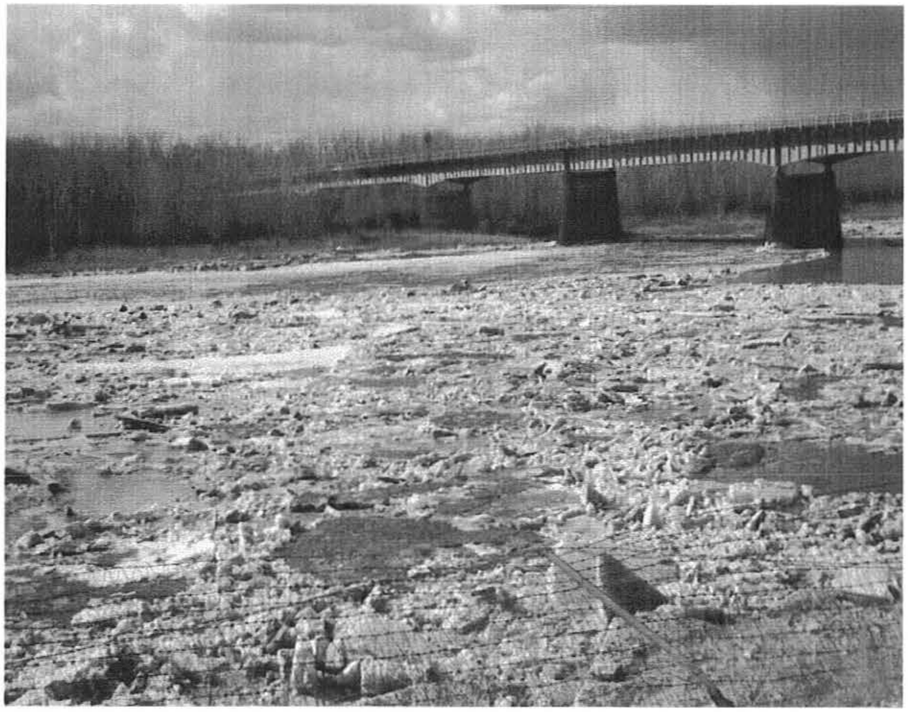

Figure 8. Photograph of the Yellowstone River on March 20, looking northwest from near the Bell St. bridge (not shown in photograph) toward the Business 94 bridge in Glendive.

Figure 9. Photograph of the Yellowstone River on March 20, looking west along the Bell St. bridge (at left of photograph) in Glendive.

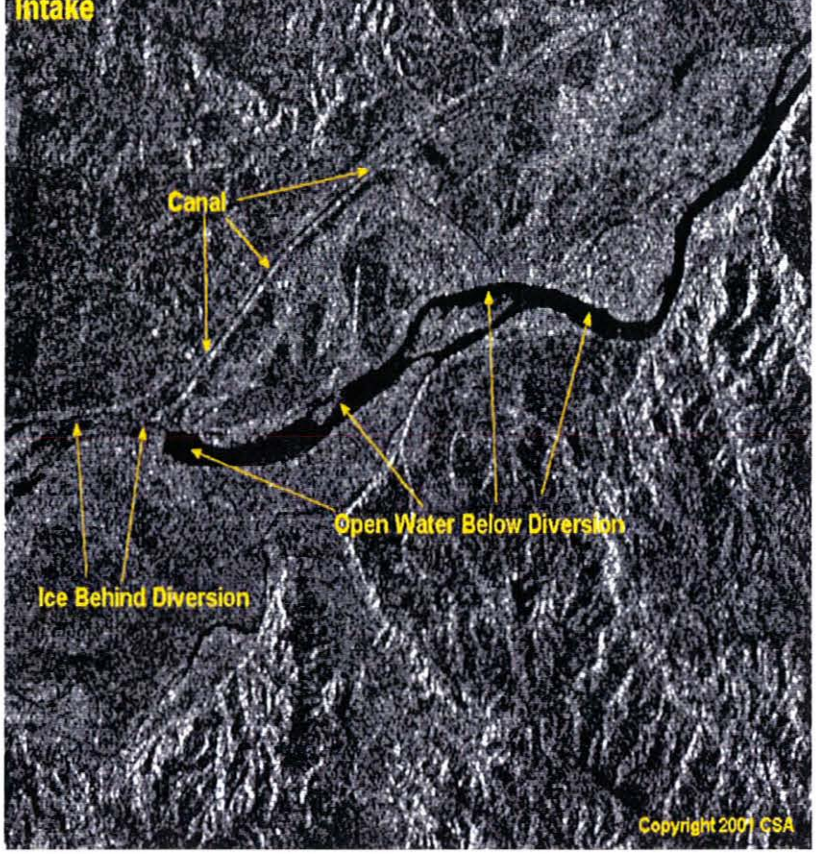

Figure 10. RADARSAT image from March 23 at 5:47 p.m. MST. The image has been cropped, highlighted, and magnified in the vicinity of Intake, Montana, north of Glendive. Note the ice behind the diversion dam and the open water downstream of the dam.

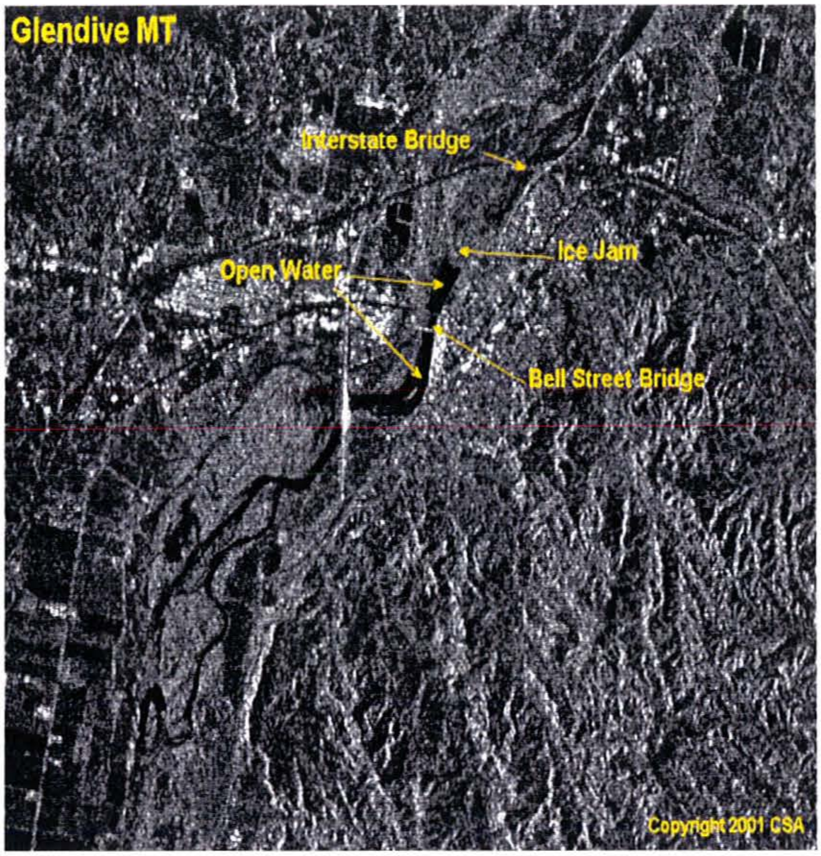

Figure 11. RADARSAT image from March 23 at 5:47 p.m. MST. The image has been cropped, highlighted, and magnified in the vicinity of Glendive. Note the ice jam downstream of the Bell St. bridge.

Figure 12. Photograph of the Yellowstone River from the "Glendive Camera" on March 23 at 11:49 a.m. MST looking north. The Business 94 bridge is in the foreground. Note the ice upstream at the top of the photograph. The ice is the back edge of the ice jam seen in Figure 11.