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AN OPERATIONAL ASSESSMENT OF THE MODIS FALSE COLOR COMPOSITE WITH THE GREAT FALLS, MONTANA NATIONAL WEATHER SERVICE

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ABSTRACT

The close and productive collaboration between the National Weather Service (NWS) Weather Forecast Office (WFO) in Great Falls, MT and the Short Term Prediction and Research Transition (SPoRT) Center at NASA/Marshall Space Flight Center has presented an opportunity for science and technology sharing. SPoRT has provided a false color composite product derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data, part of NASA's Earth Observing System. This product is designed to distinguish snow and ice covered ground from bare ground and clouds.

The Great Falls WFO has been a test bed of the MODIS false color composite as an operational tool to monitor the development and dissipation of snow cover. Preliminary applications have shown the product can be used to monitor snow cover in remote locations as well as river and lake ice. This information leads to improved assessments of flooding potential during post snow-event conditions where rapid melting and runoff are anticipated. Deriving similar products from future geostationary satellites may contribute to the NWS mission by enhancing situational awareness.

The operational use of this product was transitioned to the Great Falls WFO through a process of product implementation, discussions with the service hydrologist, and post event analyses. An assessment period from January to March 2008 was initiated to investigate the impact of the false color product on WFO Great Falls' operations. This paper will emphasize the impact the false color product has in the WFO's hydrologic situational awareness and how this information can be used to influence operational decisions.

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1. INTRODUCTION

The National Weather Service Weather Forecast Office in Great Falls, Montana (TFX) has partnered with scientists from NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. A small group of scientists from NASA have formed the Short-term Prediction Research and Transition Center. SPoRT seeks to accelerate the infusion of NASA earth science observations, data assimilation and modeling research into NWS forecast operations and decision-making (Goodman et al., 2004).

The TFX location provides a unique opportunity for using NASA's polar orbiting instruments. The area of interest for TFX lies at about 47°N, a relatively high latitude for the application of Geostationary Operational Environmental Satellite (GOES) imagery. The weakness is that the footprint of the GOES measurement is oblique and appreciably larger in the north-south direction at higher latitudes than those directly under the satellite at the equator. The problem is compounded by the fact that the TFX area of interest is 25-35° longitude away from the center of both the GOES East and West satellites. Again, the result is a larger footprint, but this time in the east-west direction. As a result, small scale features are "blurred" to some degree once remapped to the users display system; the increased area of the satellite footprint is forced into a more appropriately proportioned map. The polar-orbiting instruments on NASA's Earth Observing System (EOS) satellites provide a higher resolution image and a truer footprint than current GOES satellites. In undertaking this assessment, TFX and SPoRT began to research how EOS data may be utilized to better monitor the small-scale changes in snow and ice cover at high latitudes that fall between the GOES satellites.

The collaboration between NASA atmospheric scientists and NWS meteorologists has provided forecasters several unique datasets to use during forecast and warning operations (Darden et. al., 2002). The MODIS false color composite is one of these unique data sets. The MODIS false color composite was first introduced to the Great Falls WFO in 2004 and added to previous efforts by TFX to use remote sensing information as in Miller (2003). False color composite imagery has found wide use among the forestry and fire weather community in showing the extent of burn areas. The rural nature and low population density of Montana create similar difficulties in evaluating the breadth and retreat of snowfall and river ice. Remote sensing provides the best opportunity to accurately and routinely determine the extent and transition of snow cover and river ice in remote areas. However, using visible imagery, it is often difficult to differentiate snow from clouds. TFX has been evaluating the use of the MODIS false color composite to monitor the development and dissipation of snow cover and river ice. The false color composite has led to improved assessments of flooding potential in Montana, particularly during post event conditions where rapid melting and runoff are anticipated.

2. BACKGROUND

The MODIS false color product combines, or “composites”, one visible channel with two shortwave infrared channels to highlight features with infrared signatures. This particular false color composite has been developed to distinguish between snow and clouds, both of which appear white in standard visible imagery. While snow may look like clouds in visible imagery (i.e. what our eyes see), snow radiates differently than clouds in other portions of the spectrum. Spectrally, snow is different from clouds at wavelengths greater than 1.4 μm (Figure 1). MODIS channels at 1.63 and 2.13 μm can therefore be used to distinguish between snow and cloud cover. To make this distinction more obvious, a visible channel combined with the 1.63 and 2.13 μm channels is used to produce the “false color” image. The MODIS imagery is further enhanced using a contrast stretch which redistributes the grey values of the image improving the image contrast and assuring a good color differentiation between various features of interest (CCRS, 2005).

Figure 2 provides an example of the false color composite (Figure 2.1) compared to standard visible imagery (Figure 2.2) and a natural color composite (Figure 2.3). The false color image combines MODIS data such that features with large reflectance in the visible, 1.63μm, and 2.13μm channels take on color characteristics corresponding to red, green, and blue, respectively. Green indicates clear skies and no snow cover, white indicates water clouds, while pink indicates clouds with ice. Finally, red indicates snow cover and dark red to brown indicates snow in forested areas. While cloud movement in standard visible imagery animations does allow some distinction between snow cover and clouds, the false color product enhances the distinction between snow and clouds in a single image.

3. UTILITY IN FORECAST DECISION MAKING

While the MODIS false color imagery is used primarily in the initial steps of the decision making process, it has value throughout the forecast process. It often complements the traditional products and methods for monitoring the change in snow and ice cover as in Hall and Riggs (2007). For example, a conventional method to differentiate clouds from snow cover is to animate the GOES visible imagery and compare the stationary white areas of snow to the moving white clouds.

The MODIS false color imagery is produced by polar orbiting satellites at a 500 meter resolution. This provides greater clarity than the 4 km GOES visible imagery even though only 1 or 2 images are available per day.

The clarity of the MODIS false color imagery has helped the TFX WFO decrease the dependency on point observations of snow cover and significantly lessen the need to use additional human resources to survey rural locations during large snowfall events. This conforms to an NWS regional goal to increase personnel safety by decreasing travel during potentially dangerous weather situations. Further, there is a reduced need to individually contact cooperative observers and weather spotters via phone requesting additional snow cover information. Essentially, TFX has found the MODIS false color imagery to be a convenient product that saves time and human resources.

The greatest value of the product for TFX has been to evaluate the extent and change of snow cover. This process allows forecasters to assess the potential for local flooding due to rapid melting or ice jams. In addition to the conventional use of visible imagery, there are various observation networks (cooperative observers, Snowpack Telemetry (SNOTEL), state Department of Natural Resources and Conservation (DNRC), etc.) that provide snow depth and/or accumulation observations. However, these are point observations that require some assumptions in order to develop a 2-dimensional spatial analysis of snow cover. Often, human observers are called upon to make measurements of snow depth and snow water equivalent. At times NWS personnel may go to rural areas to survey snow cover extent. The MODIS false color image eliminates some of the previously necessary assumptions and better fills data void areas while providing information on features not well captured by lower resolution remote sensing instruments.

To determine flooding potential from snowmelt, TFX uses the MODIS false color imagery by looking for significant changes in snow cover. The forecasters monitor the change in extent of the red (snow cover) regions in the false color product. An improved awareness of the flooding potential is achieved by combining the MODIS false color imagery with snow depth and snow water equivalent information from SNOTEL sites and modeled products from the National Operational Hydrologic Remote-Sensing Center (NOHRSC) (Figure 3.1).

The high resolution of the MODIS false color imagery has improved the ability of TFX forecasters to identify changes in snow cover over short periods of time. Previously, localized flooding of small basins was difficult to identify in a timely manner with lower-resolution products from GOES and NOHRSC. When high values of snow water equivalent are indicated in the same area as large snow cover changes, TFX will examine specific stream gages for changes in flow or water level. TFX is able to more quickly inform state and local emergency management officials and can be more specific in its forecast area of concern by using the false color imagery throughout the decision making process.

Snow accumulations over the Great Plains and inter-mountain west can be large and remain on the ground for extended periods of time. Conversely, the snow cover may melt in a matter of days with Chinook wind events. The MODIS false color imagery is useful throughout the winter season due to the cyclical nature of freeze/thaw events over eastern Montana.

In 2004 a large snow event affected northeast Montana (Figure 3.2). Modeling and forecasts of the snowmelt suggested potential flooding along the Milk, Poplar and Missouri Rivers and adjacent tributaries. The false color images over the course of the following month show a gradual melting of the snow, first occurring to the south of the Missouri and Milk Rivers and then later north of the rivers (Figure 3.3). Observing this gradual trend indicated that the predicted flooding would be less than anticipated. Additional information on this event is available in Adolphson et al. (2005).

4. JANUARY – MARCH, 2008 EVALUATION

During the late winter and early spring of 2008, TFX provided detailed assessments of the MODIS false color imagery product for monitoring changes in snow cover as it relates to potential flooding. Specifically, two events occurred; one from 13 February – 2 March and the second from 4 – 12 March. A significant snow event on 13 February covered much of Montana east of the Continental Divide. The snowfall accumulations varied from 2 to 5 inches. A clear view from MODIS on 14 February shows the full spatial extent of snow cover (Figure 4.1). The primary concern was the predicted onset of warmer temperatures. This warm-up would melt the recent snow, sending the water into ice-covered streams resulting in potential flooding.

Cloud cover is the major limiting factor of the MODIS imagery; however, TFX was still able to glean valuable information. Despite the limited clear skies for several days, a noticeable, small-scale area of melting had occurred east of the Rocky Mountain Front by 16 February (Figure 4.2) between Cut Bank and Great Falls, a rural area with few snow depth observations. MODIS imagery showed that fresh snow fell in this same area the next day (Figure 4.3). The mesoscale spatial detail of snow cover provided valuable information, allowing the hydrologist to assess how the area of melting and subsequent replenishment of snow may add to stream and river water levels. By 19 February (Figure 4.4) a nearly complete view of Montana showed that melting had mostly occurred in central Montana and adjacent to the Rocky Mountain Front. Cooler temperatures in eastern Montana resulted in a slower melting of snow cover in that area. The ability to observe the snow cover retreat decreased the concern for flooding of ice-covered streams and resulted in only a mention of possible ice jamming on smaller streams in the Hazardous Weather Outlook product issued by TFX rather than the issuance of any flood watches or warnings. In addition, the false color imagery clearly showed that Canyon Ferry Reservoir in central Montana and Fort Peck Reservoir in eastern Montana remained ice-covered, decreasing the concern for ice jams in these and surrounding areas. It would take nearly 2 weeks more (2 March, Figure 4.5) before the remaining snow cover in eastern Montana melted. During this time, stream flows showed no significant change, as was expected given the slow change in snow cover observed in the false color imagery. Further, the imagery indicated reservoirs were only slowly showing signs of thermal ice rotting.

The second event began on 4 March with snow falling in a wide area of central and southeastern Montana, but snow water equivalent amounts were 0.10 inches or less. This posed little concern based on TFX's past experiences of rapid melting with such events. However, the false color imagery suggested that the ice on the reservoirs and rivers was beginning to experience thermal rotting (Figure 4.6). To confirm this, TFX used the MODIS natural color composite to look for white areas of ice on the water surfaces. From 8 – 10 March the natural color imagery confirmed that ice still existed, but by 12 March a reduction in the ice was evident. At the same time the elevated valleys in southwest Montana, as well as the southern slopes in the mountainous regions, had decreasing snow cover observed in the false color imagery (Figure 4.7). TFX noted that some indications of ice movement on northern rivers and tributaries could be seen. However, this did not become a large concern as cold temperatures remained for several more weeks, preventing any rapid or early melting of snow and river ice.

5. SUMMARY

The MODIS false color composite, provided to the Great Falls, MT WFO by the SPoRT Center has enhanced the situational awareness capabilities of the forecasters. The MODIS false color composite takes advantage of the different emission wavelengths of snow and cloud cover creating a product that clearly identifies snow cover in red, while clouds remain white. This clear difference, combined with a resolution of 500 m provides the Great Falls WFO forecasters a vital tool in monitoring the spatial extent of snow cover as well as ice cover in rivers and reservoirs.

The MODIS false color composite can be limited by cloud cover obscuring surface features and does not provide a predictive element of how snow cover will change. Additionally, while the product shows the extent of the snow cover, it does not provide any information on the water equivalent of the snow. The imagery's true value is providing forecasters with information in rural and remote regions, at better resolution than current tools, thereby reducing manpower needs and improving the efficiency of the forecast process. All these features allow the forecasters to monitor the changes in snow and ice cover extent that lead to improved forecasts of flooding potential from snowmelt. Further, observations using the MODIS false color composite imagery can improve forecast confidence in reducing the threat of flooding if the snowmelt is observed to be gradual.

6. REFERENCES

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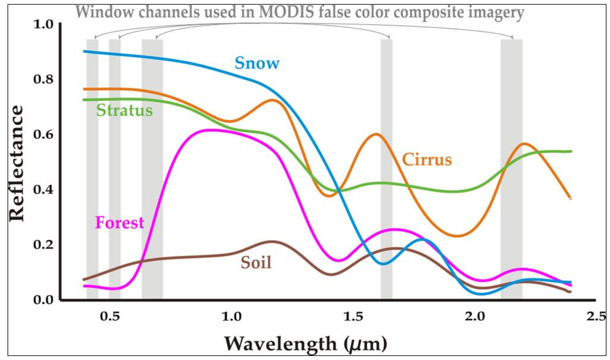

Figure 1. Typical reflectance for naturally occurring features.

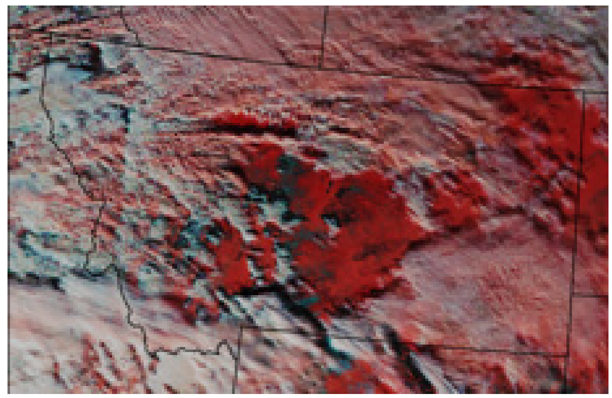
Figure 2.1. Example of the MODIS false color image. Reds indicate snow on the ground, white indicates cloud cover, and greens indicate clear ground.

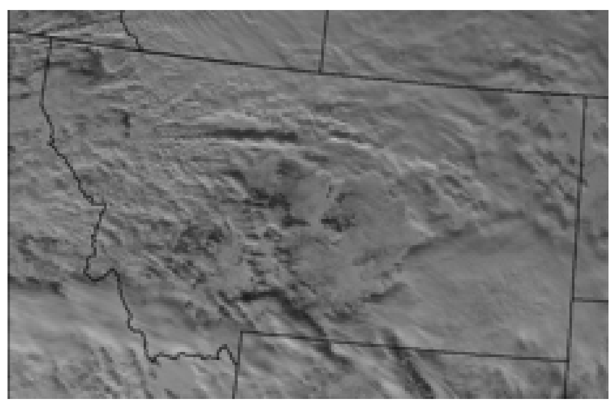
Figure 2.2. MODIS visible image corresponding to the same view shown in Figure 2.1.

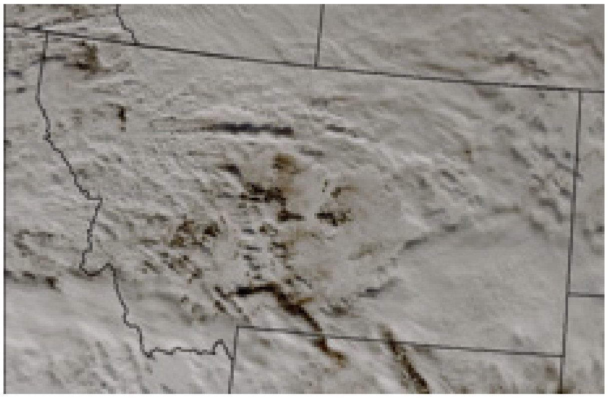

Figure 2.3. MODIS natural color composite image that shows colors as they would appear to the human eye corresponding to the same time in Figures 2.1 and 2.2.

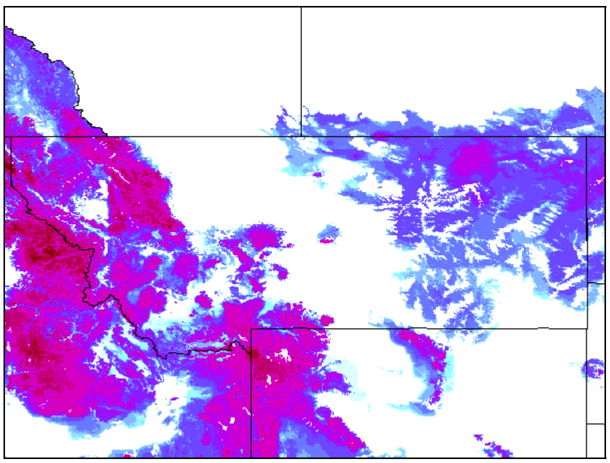

Figure 3.1. February 19, 2004 – NOHRSC Modeled Snow Water Equivalent.

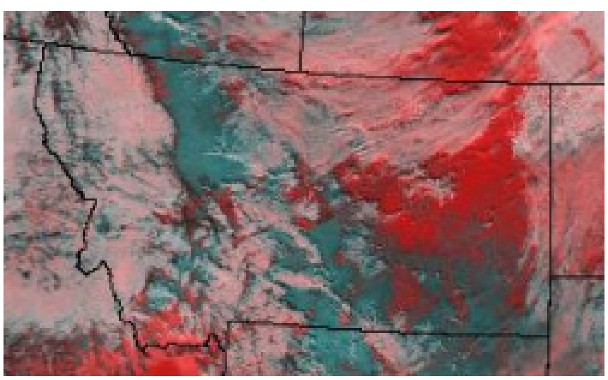

Figure 3.2. MODIS false color composite for Montana on February 19, 2004. The main item of interest is the large amount of snow cover in northeast and eastern Montana.

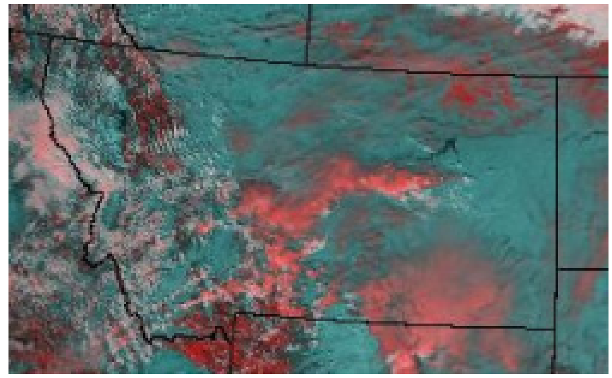

Figure 3.3. Same as Figure 3.2, but taken on March 25, 2004 after most of the snowmelt.

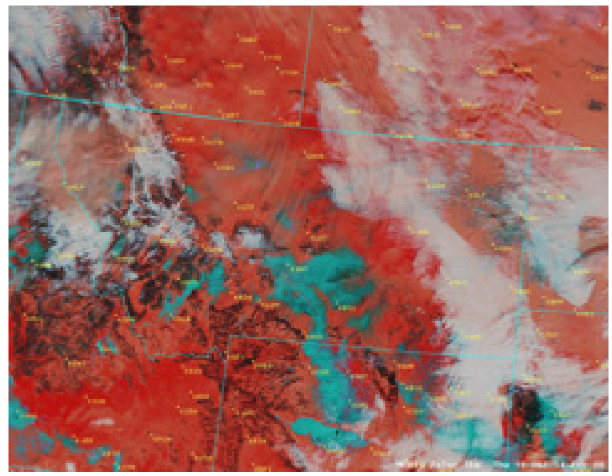

Figure 4.1. MODIS false color composite showing widespread snow cover across Montana for the event beginning on February 14, 2008.

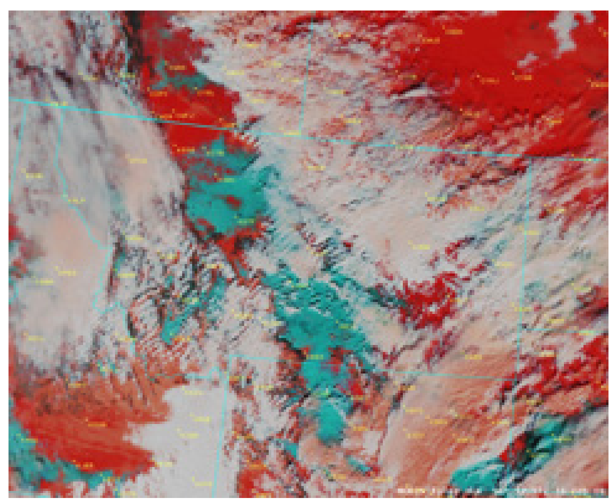

Figure 4.2. Same as Figure 4.1, but for February 16, 2008.

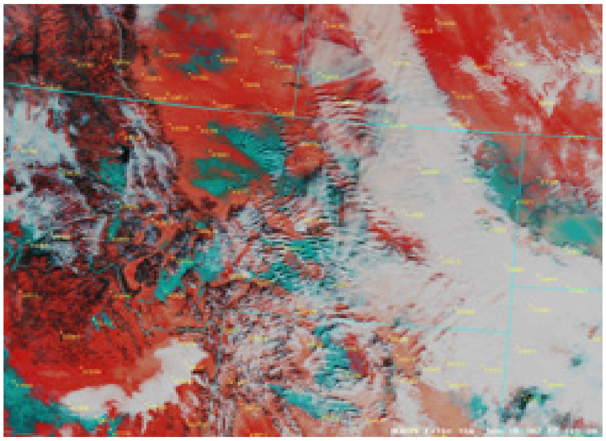

Figure 4.3. Same as Figure 4.1, but for February 17, 2008.

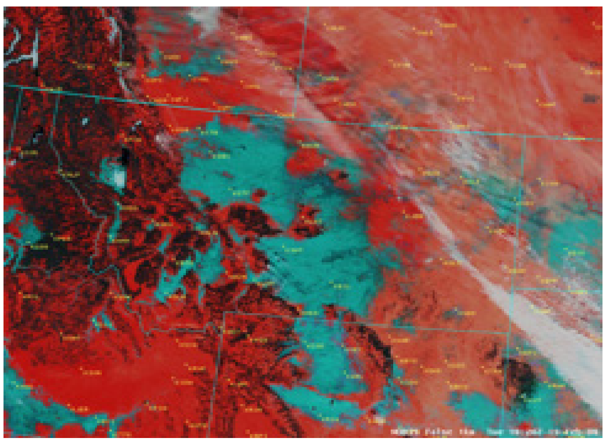

Figure 4.4. Same as Figure 4.1, but for February 19, 2008 as snow cover begins to melt.

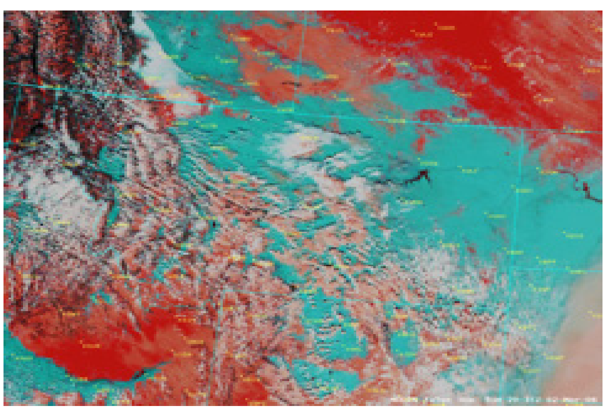

Figure 4.5. Same as Figure 4.1, but for March 2, 2008. Remaining snow cover has nearly all melted at this point.

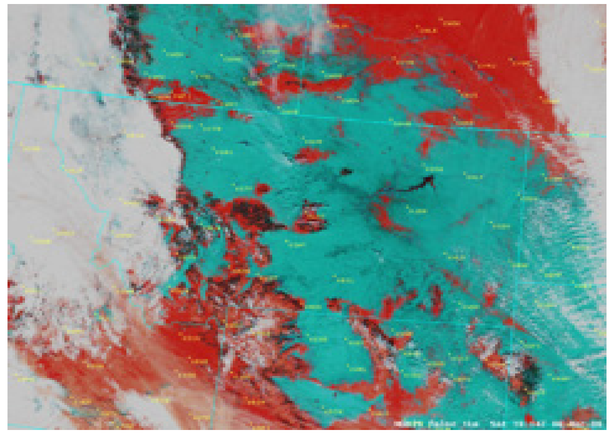

Figure 4.6. A second event began on March 4, 2008. Snowfall was light, but ice was built up on the rivers and reservoirs. By March 8, 2008, shown here, the ice was beginning to clear.

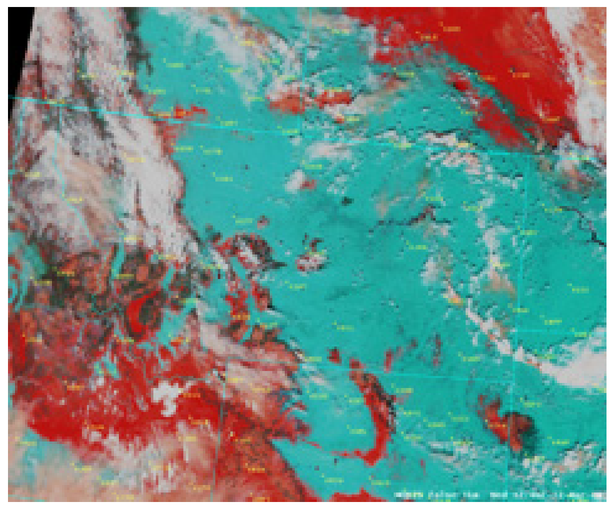

Figure 4.7. Same as Figure 4.6, but for March 12, 2008. Snow cover in eastern Montana has melted and the waterways showed ice movement, but nothing significant.