USING GIS AND GOOGLE EARTH FOR THE CREATION OF THE GOING-TO-THE-SUN ROAD AVALANCHE ATLAS, GLACIER NATIONAL PARK, MONTANA, USA

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ABSTRACT: Snow avalanche paths are key geomorphologic features in Glacier National Park, Montana, and an important component of mountain ecosystems: they are isolated within a larger ecosystem, they are continuously disturbed, and they contain unique physical characteristics (Malanson and Butler, 1984). Avalanches impact subalpine forest structure and function, as well as overall biodiversity (Bebi et al., 2009). Because avalanches are dynamic phenomena, avalanche path geometry and spatial extent depend upon climatic regimes.

The USGS/GNP Avalanche Program formally began in 2003 as an avalanche forecasting program for the spring opening of the ever-popular Going-to-the-Sun Road (GTSR), which crosses through 37 identified avalanche paths. Avalanche safety and forecasting is a necessary part of the GTSR spring opening procedures. An avalanche atlas detailing topographic parameters and oblique photographs was completed for the GTSR corridor in response to a request from GNP personnel for planning and resource management. Using ArcMap 9.2 GIS software, polygons were created for every avalanche path affecting the GTSR using aerial imagery, field-based observations, and GPS measurements of sub-meter accuracy. Spatial attributes for each path were derived within the GIS. Resulting products include an avalanche atlas book for operational use, a geoPDF of the atlas, and a Google Earth flyover illustrating each path and associated photographs. The avalanche atlas aids park management in worker safety, infrastructure planning, and natural resource protection by identifying avalanche path patterns and location. The atlas was created for operational and planning purposes and is also used as a foundation for research such as avalanche ecology projects and avalanche path runout modeling.

1. INTRODUCTION

In 2003, a formal avalanche forecasting program was instituted in Glacier National Park (GNP), Montana, under cooperation with the U.S. Geological Survey (USGS) Northern Rocky Mountain Science Center and the National Park Service. This program was created to ensure worker safety during the annual spring opening of the immensely popular Going-to-the-Sun Road (GTSR). The GTSR is an 80 kilometer road that traverses through the central portion of GNP from West Glacier in the west to St. Mary east of the Continental Divide. GNP officials close 56 kilometers of the road in the winter due to abundant snowfall, adverse weather conditions, and avalanche hazard. Snow removal operations begin annually on 1 April.

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Road opening dates vary due to seasonal snowfall, avalanche hazard, and personnel logisitics. The median opening date for the GTSR is 9 June (from 1933 – 2010). Avalanches are the primary hazard affecting spring opening operations as the GTSR traverses through 37 known avalanche paths (Figure 1).

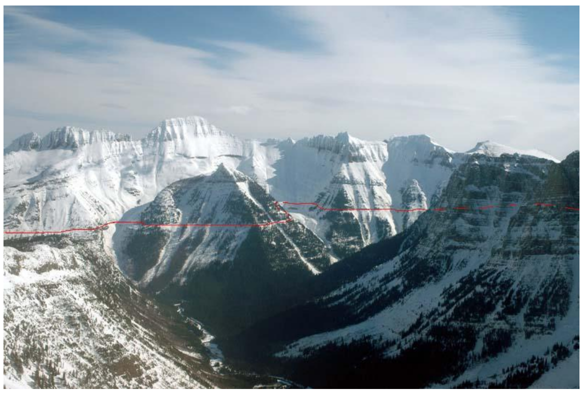


Figure 1: Figure 1: The red line is the location of the GTSR as it traverses through the track of avalanche zones on the west side of the Continental Divide. Photo: Blase Reardon.

Reardon and Lundy (2004) document the details of snow removal operations and avalanche hazards along the GTSR and the USGS/GNP Going-to-the-Sun Road Avalanche Program in depth. One of the initial objectives of the program was to create an avalanche atlas that details every avalanche path affecting the GTSR. An initial avalanche atlas database design was created in 2003. However, a more formal and concentrated effort began in the spring of 2008.

The GTSR avalanche atlas was designed to address three key objectives: GNP Roads Department worker education and safety, GNP infrastructure and resource management, and a foundational database for avalanche research. The GNP Roads Department workers are trained in avalanche safety and rescue, and have dozens of years of informal historical records and anecdotes regarding avalanche path names and locations. The avalanche atlas provides a concrete visual and spatial means to safely and properly strategize their work plan in conjunction with the daily avalanche hazard forecast. The avalanche atlas also aids GNP engineers and landscape architects in planning for reconstruction of the GTSR. Finally, the avalanche atlas provides a foundation for further avalanche research using GIS, including historical runout modeling as well as avalanche ecology and dendrochronology projects.

The use of GIS and avalanche studies is far-reaching. GIS has been used for avalanche hazard mapping and risk analysis (Furdada et al., 1995; Cappabianca et al., 2008; Teich and Bebi 2009), runout modeling (Reardon et al., 2008; Delparte et al., 2008), characterizing spatial extents of avalanche paths (Stoffel et al., 1998; McCollister et al., 2003), and geomorphological change associated with avalanches (Walsh et al., 1994; Reardon et al., 2008; Teich and Bebi, 2009). The use of GIS is inherent in the creation of the GTSR atlas through geodatabase management and visualization.

2. CREATING THE AVALANCHE ATLAS

The initial avalanche atlas was constructed in a MS Office Access (v. 2003) database listing major avalanche paths based upon historical references and field observations. During the spring of 2008 oblique photographs were obtained for each avalanche path. The above average snowfall throughout the winter of 2007-08, and cool, wet spring adequately filled all of the avalanche paths affecting the GTSR. This allowed for identifiable photographs depicting all avalanche paths, even those that affect the GTSR only during years with above average snowfall. Photographs were taken from vantage points where at least 75 percent of the avalanche path was visible or the starting zone to the area of the GTSR that the avalanche path affects (Figure 2).

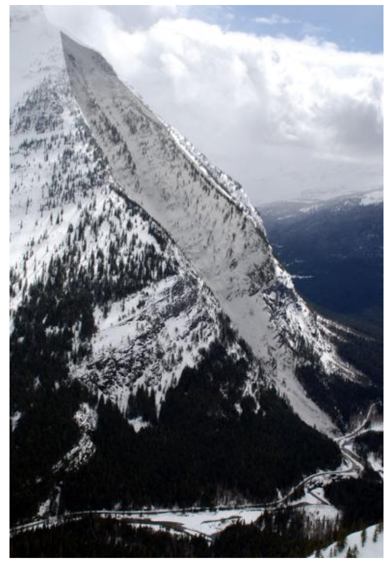


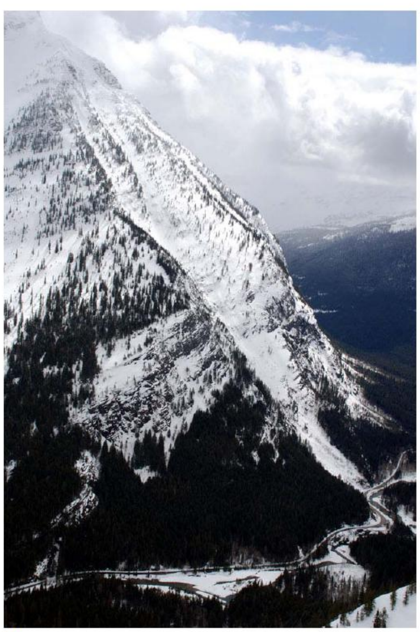
Figure 2: Oblique photograph of the Red Rock avalanche path and the GTSR. Workers can see ~ 20% of the path from the GTSR.

During the photographing campaign, 37 major avalanche paths were identified as affecting the GTSR. Some have multiple starting zones that funnel to one central location along the GTSR, but these are identified as sub-paths of the major avalanche path in which they are contained. Using ESRI ArcGIS 9.1 software, the avalanche paths were identified using USDA Farm Services Agency National Agriculture Imagery Program (NAIP) 2005 imagery. The avalanche paths were digitized within a GIS using the imagery as a baseline as well as terrain parameters such as slope. Questionable areas in runout zones or where the avalanche paths crossed the road were field verified using sub-meter accuracy Trimble Geo XH handheld GPS units. The digitization also relied heavily on field observations and notes from avalanche forecasters since 2003.

Once the avalanche paths were digitized, various zonal statistics were calculated for each path using ArcGIS Spatial Analyst. Topographic parameters such as slope, elevation, and aspect were calculated using a 10 meter Digital Elevation Model (DEM). For each individual avalanche path, an oblique photograph and the following topographic metrics and information are provided:

1. Milepost along the GTSR
2. Geographic coordinates (decimal degrees)
3. Start zone elevation (m)
4. Runout zone elevation (m)
5. Vertical fall (m)
6. Path length (m)
7. Start zone aspect (cardinal directions)
8. Slope angles of start zone, track, runout, and overall slide path (degrees)
9. Detailed description of start zone, track, and runout zone (degrees)
10. The length of the GTSR that is affected by the path (m)
11. The primary type of avalanche that affects the avalanche path during spring opening operations
12. The primary time that the avalanche path melts out during spring opening operations
13. The overall general hazard rating (i.e. the severity of hazard it poses to workers on the GTSR)
14. General comments

The information was compiled and presented in a hard copy version that was distributed to GNP personnel (Figure 3)



01
Red Rock Slide

Avalanche Path: Red Rock Slide **Number: 01**
Zone: West Side

Location:
GSTR Mile Post: 17.35
Map Coordinates: 48.693 N / -113.816 E

Description of Terrain:

Starting Zone Elevation:	2120 m
Runout Zone Elevation:	1058 m
Vertical Fall:	1062 m
Length of Path:	1735 m
Aspect of Starting Zone:	WNW

Angles of -

Starting Zone:	41 deg	*Track:*	21 deg
Runout Zone:	15 deg	*Slidepath:*	34 deg

Starting Zone: Open slope that funnels into 3 separate chutes which is affected by afternoon sun during the plowing season. Unable to see start zone from road below path.

Track: Composed of 3 chutes that funnel into one craggy chute with small trees and cliffs throughout. About 1/2 of the track is visible from the road at Red Rock Point.

Runout Zone: Steep runout consisting of the GTSR and McDonald Creek. Terrain trap.

Avalanche Characteristics:

Length GTSR Affected:	131 m
Primary Avalanche Type:	Loose
Time of Plow Season Path Melts Out:	Early
Relative Hazard Rating:	Low

Comments: This path is apt to slide after new snowfall at the onset of solar input. Because of the narrow confines of the runout zone, debris tends to accumulate on the road and in McDonald Creek in a classic terrain trap.

01
Red Rock Slide

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Figure 3: Excerpt from GTSR Avalanche Atlas detailing topographic parameters of each individual avalanche path and associated oblique photograph.

An overview of all of the avalanche paths along the GTSR was exported to a GeoPDF using a free toolbar from TerraGo Technologies that allows one to export a map into a GeoPDF. This allowed us to share an overview or a more detailed portion of a few avalanche paths with non-GIS users. The user need only to click on the colored polygon representing the avalanche path and the attributes contained in the full avalanche atlas appear on the screen. The resultant .pdf file is small in size (as compared to a 125 page document) yet still contains all of the attributes of all avalanche paths as well as a hyperlink to the oblique photographs of each avalanche path, which is hosted on our USGS NRMSC website (http://nrmsc.usgs.gov/image/tid/139).

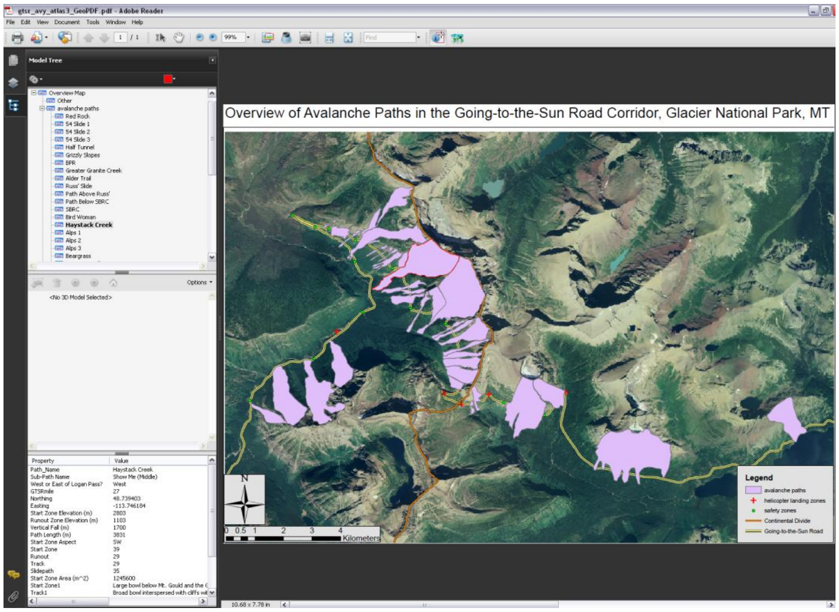

Figure 4: A screen capture of the GeoPDF of the avalanche atlas. The Little Granite avalanche path perimeter is highlighted in red and the attributes are displayed in the lower left corner of the image.

Finally, a shape-file of the avalanche path polygons was imported into Google Earth software (v 5.0) and a flyover tour of the GTSR avalanche paths was created. Google Earth Pro (v 5.0) was used to record this tour in an editable movie file format. The movie was edited and oblique photographs were inserted to create a flyover movie of the GTSR avalanche paths (http://nrmsc.usgs.gov/research/gtsr_aval/video_FULL). An overlay of the GTSR avalanche paths was created in this process and stands alone as a .kmz or .kml file for users of Google Earth.

3. PRODUCTS AND OUTREACH

Creating the GTSR avalanche atlas resulted in the creation of a formal avalanche atlas, a GeoPDF of the avalanche paths, avalanche path overlays for Google Earth, and a Google Earth Flyover movie. This suite of products fulfilled the three objectives of the creation of such an atlas. The formal atlas allowed GNP personnel to have a more explicit understanding of the avalanche hazard along the GTSR from a spatial perspective. Avalanche specialists used the atlas for training of new employees in the GNP Roads Department. Veteran road workers were also able to gain insight to the magnitude of the avalanche paths in which they work and travel. The atlas also helped the Roads Department foremen plan each day's tasks in conjunction with the daily avalanche advisory.

Avalanches impact the GTSR on a regular basis by decimating the road and the historic rock wall. The alpine section of the GTSR is currently undergoing major reconstruction, and the atlas helped GNP engineers and landscape architects and U.S. Department of Transportation Federal Highway Administration engineers in discerning locations to rebuild and reinforce historic rock wall segments along the road. The atlas is currently being implemented in plans for the major decade-long reconstruction of the GTSR.

The geodatabase of the avalanche paths along the GTSR serves as the foundation for the avalanche atlas and a rich data source for avalanche-based research. The dataset is currently being used in a study investigating the ecological response to a large magnitude avalanche event (Fagre and Peitzsch 2010). Tree-ring data and vegetation regrowth are being analyzed spatially to determine avalanche frequency in paths along the road and the effect of avalanches on the local landscape. The geodatabase could also be used in conjuction with weather and avalanche programs in a GIS, such as GeoWAX (McCollister, 2008) to help avalanche forecasters along the GTSR.

An unexpected outgrowth of the avalanche atlas manifested itself in the form of public outreach. The local community and GNP personnel in general became interested in the avalanche atlas, and it became clear that a product to interface with the public was needed. Google Earth provides a free and easily interpretable means for the public to digest spatially explicit information. The creation of the Google Earth avalanche path overlays and the flyover tour movie allows the public to visualize the avalanche paths along the GTSR. The GTSR avalanche atlas has proven to be a useful tool in planning and research thus far and will continue to provide a foundation for future avalanche research and forecasting.

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DISCLAIMER

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