

# Glacier National Park Flooding November 2006

David Bernhardt  
NOAA/NWS Great Falls, MT

## Introduction

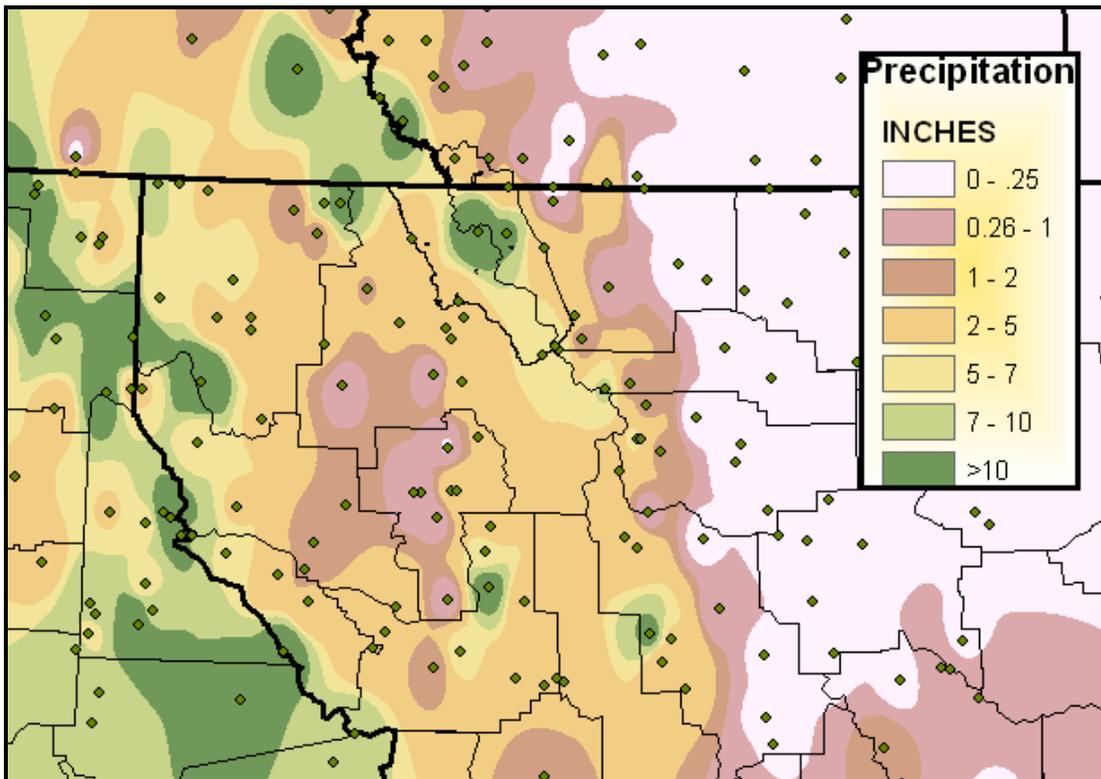
Widely fluctuating temperatures, strong jet-level winds, and a strong flow of Pacific moisture highlighted the first week of November 2006 across western Montana. The month started out cold with temperatures up to 14°C (25°F) degrees below normal and lows near -18°C (0°F) in Glacier National Park. A sharp turn-around to warmer conditions on 2 November brought typical November windiness with heavy precipitation to Glacier National Park and northwestern Montana, continuing for the next several days. New record high temperatures were set on 6-8 November at some area locations. This period also brought one of the heaviest November precipitation events to Montana. A strong westerly flow brought copious amounts of moisture from the Pacific and strong winds to higher elevations and on the lee side of the continental divide. Heavy rain fell across much of western Montana, bringing flooding and severe damage, especially to the Glacier National Park area. One weather station in the park recorded over 300 mm (12 inches) of precipitation (mostly rain) between 3-8 November. Many other higher elevation stations in western Montana recorded between 125 and 230 mm (5 and 9 inches) of rain. Valley locations received from 12 to 20 mm (0.50 to 0.75 inches) of rain. In a 24h period on 6-7 November, the Flattop Mountain SNOTEL (Snow telemetry/elev. 6300 feet) station recorded 152 mm (6 inches) of rain. This set a new November daily precipitation record for Montana. The 48h period of 6-7 November brought 230 mm (9 inches) of rain to Flattop Mountain and 185 mm (7.3 inches) to Many Glacier (on the east slopes).

A series of disturbances in the strong moisture flow combined to produce some of the most severe flooding and damage in recent memory in the park. Infrastructure within the park suffered major damage. This report will document some of the meteorological features that contributed to the major flooding. Compounding the fact that over 300 mm (12 inches) of rain fell, even at the higher elevations, the rain melted the snow that had already been on the ground. This produced a very rapid hydrologic response to rivers and lakes in the vicinity. An evaluation of numerical weather model performance during this period is also presented.

## Discussion

A nearly continuous series of storms pounded the northwest United States in early November 2006 as persistent west-southwest flow brought moisture from tropical sources to the Pacific Northwest. Figure 1 shows that the precipitation

was not limited to Montana, but extended westward to include northern Idaho and Washington, and adjacent areas in Canada. The greatest amounts recorded in Montana from 1-8 November were 368 mm (14.50 inches) at Poorman Creek SNOTEL (in the Cabinet Mountains of northwest Montana), and 292 mm (11.50 inches) at Flattop Mountain SNOTEL and 234 mm (8.80 inches) at Many Glacier SNOTEL in Glacier National Park. Precipitation accumulations dropped off dramatically in the rain-shadow areas of Alberta and Montana immediately east of the continental divide. Though precipitation was lighter, the pattern of heavy precipitation continued through 14 November. Total amounts for the first two weeks of November 2006 are shown in Figure 1. Figure 2 is an image of the topographic features in the area with place names mentioned in this paper.



**Figure 1. Total Precipitation 1-14 November 2006 across northwest Montana, northern Idaho and adjacent portions of British Columbia and Alberta.**

The upper level pattern during this period consisted of strong west-southwesterly winds (Fig. 3). This brought a nearly constant feed of moisture from the Pacific Ocean to the northwest US. Figure 4 shows the blended total precipitable water imagery from NOAA (National Oceanic and Atmospheric Administration) polar orbiting satellite AMSU (Advanced Microwave Sounding Unit) and the DMSP (Defense Meteorological Satellites Program) SSM/I (Special Sensor Microwave Imager) from 2 November through 6 November 2006. Several plumes of moisture entered the Pacific Northwest as disturbances moved through the flow. Both figures (3 and 4) show that the moisture originated in the tropics and advanced northward as stronger storm systems moved through the flow.

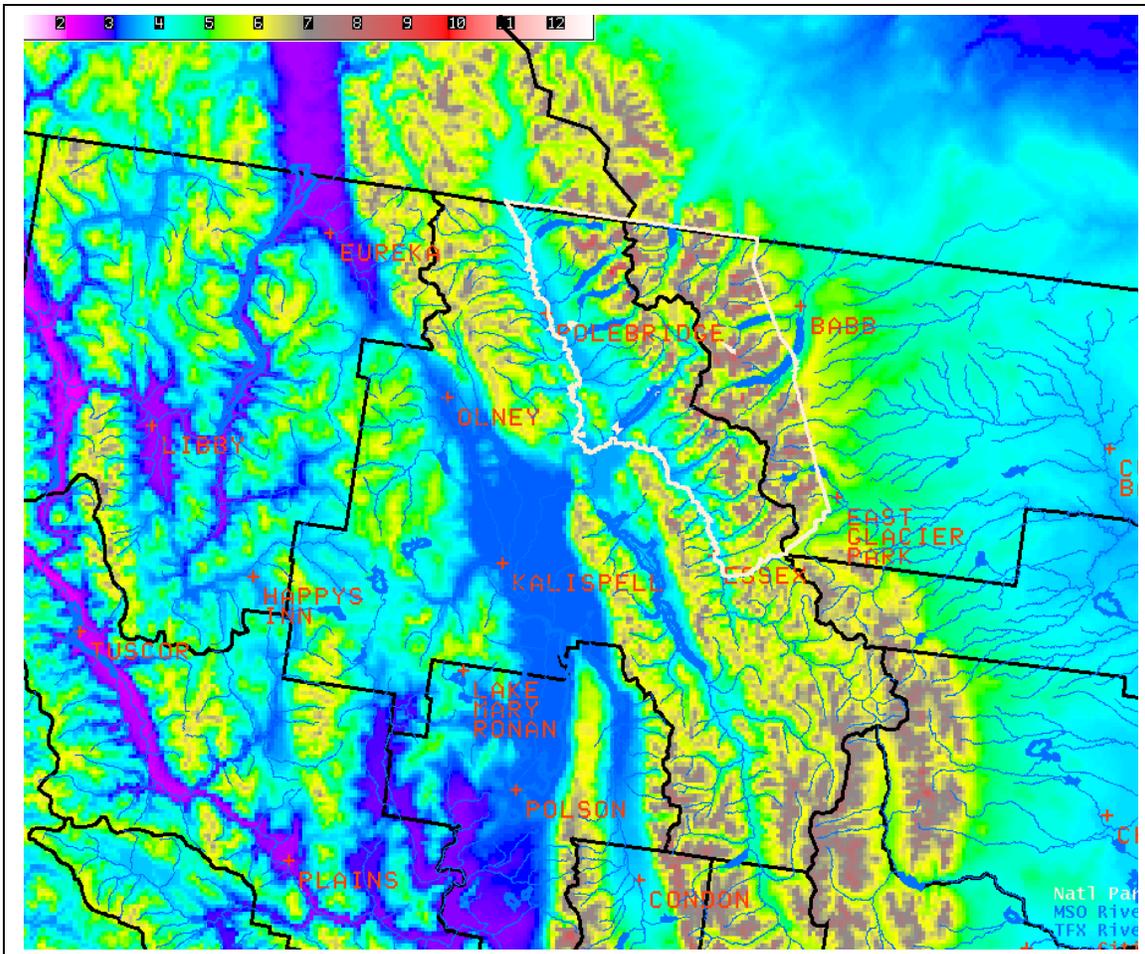


Figure 2. Topographic map of area affected by flooding. Glacier National Park is outlined in white.

Figure 5 illustrates the GOES (Geostationary Operational Environmental Satellites) West water vapor perspective during one of the heavier precipitation periods. An area of very cold cloud top temperatures over the northwest US and southern British Columbia indicates a deep layer of moisture that existed over the region at this time. A series of water vapor satellite images during this period (not shown) also indicated persistent very cold cloud top temperatures in the area, similar to that shown in Figure 5. During the period from 2 November through 7 November, very heavy precipitation fell across the area, as noted earlier. Mild temperatures accompanying the precipitation kept the precipitation in the form of rain, and melted out the antecedent 30 cm (12 inches) of snow-on-the-ground (Table 1 and Fig. 6). Temperatures remained above freezing at Flattop Mountain from the morning of 3 November through early on 8 November. The heaviest precipitation, 230 mm (9 inches), fell over a 48h period on 6-7 November. Strong westerly winds accompanied the period of heaviest precipitation. A nearby weather station at Logan Pass recorded average daily winds speeds of  $11.6 \text{ m s}^{-1}$  (26.0 mph) on 6 November,  $14.6 \text{ m s}^{-1}$  (32.7 mph) on 7 November, and  $15.7 \text{ m s}^{-1}$  (35.1 mph) on 8 November. Winds also peaked at  $53.6 \text{ m s}^{-1}$  (120 mph) at

0500 UTC 8 November (10 pm MST 7 November). Because of the strong winds, it is conceivable that not all of the precipitation collected in the rain gauges.

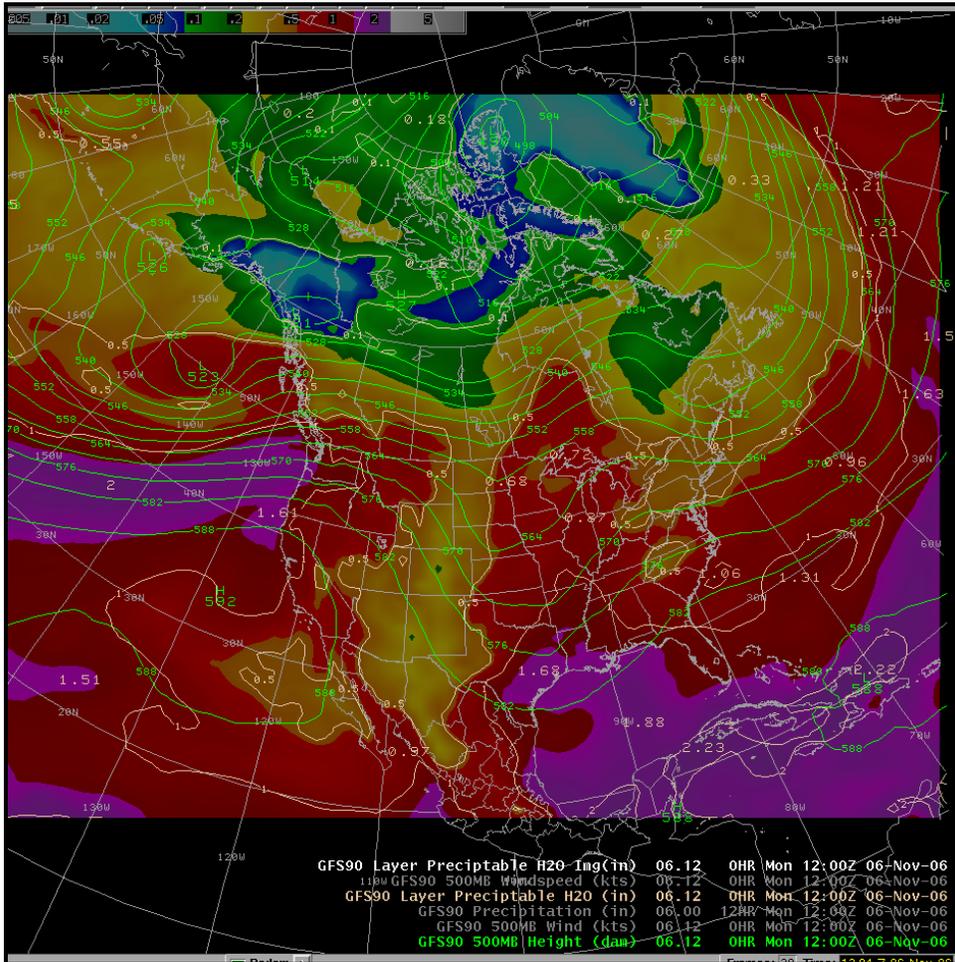
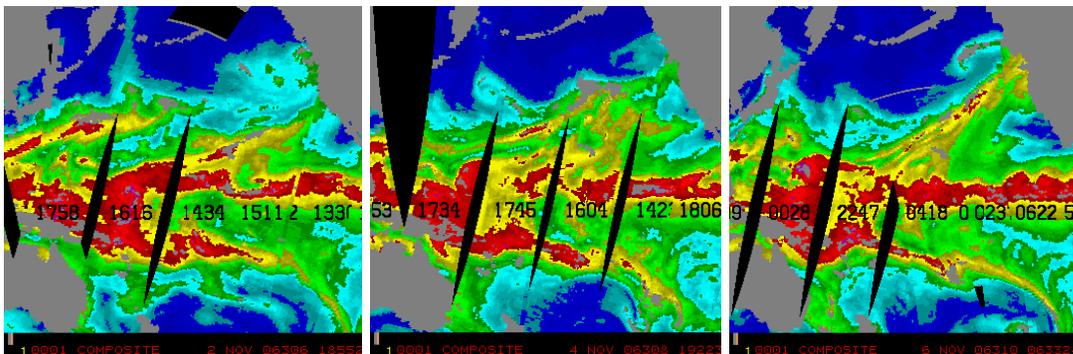


Figure 3. 6 November 2006 500 mb heights (solid lines) with 1000-500 mb layer precipitable water (inches) (color shaded) from the GFS. Note the plume of moisture (purple) from the tropics entering the Pacific Northwest.



2 November 2006

4 November 2006

6 November 2006

Figure 4. Blended NOAA AMSU and DMSP SSM/I Total Precipitable Water imagery. Note the regular plumes of moisture affecting the North America west coast. The yellows and reds are areas of precipitable water greater than 25 mm (1 inch) (CIRA).

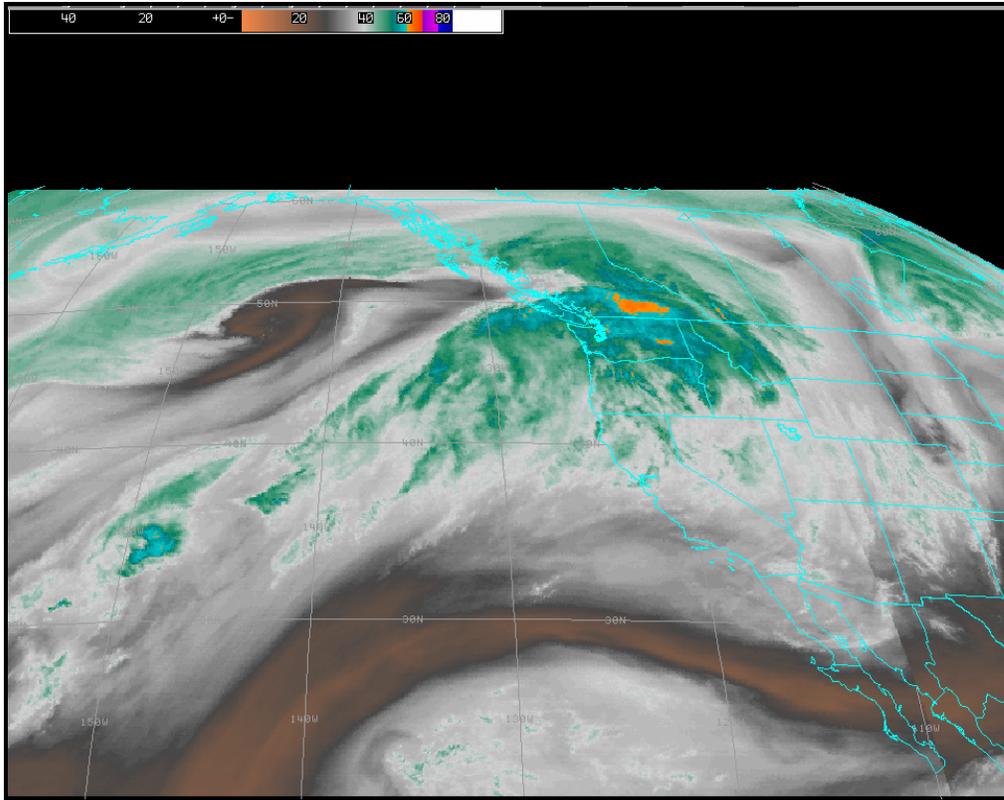
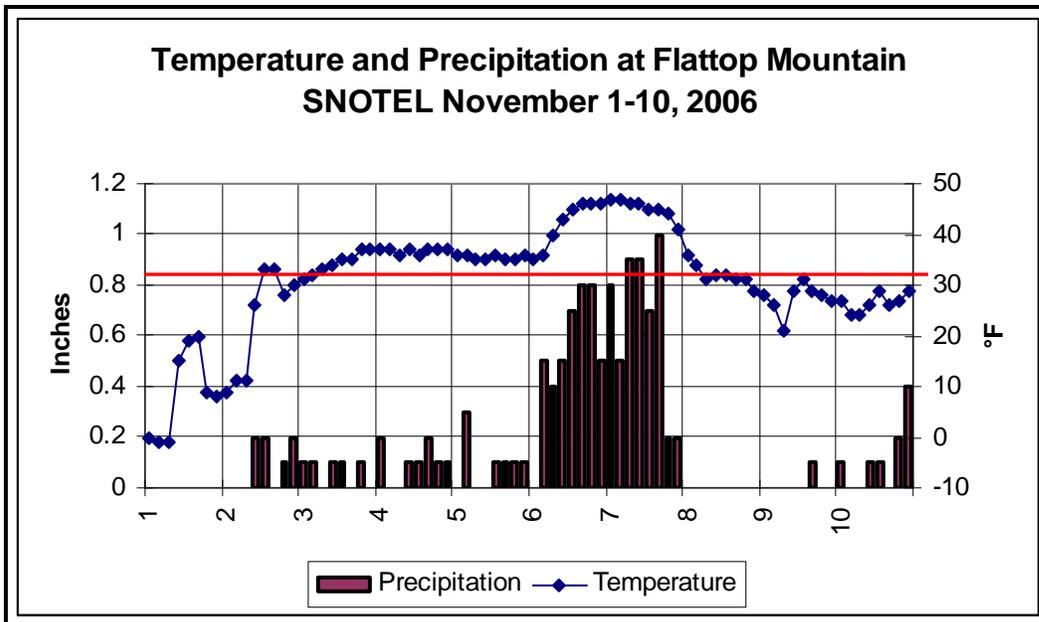


Figure 5. GOES Water Vapor Imagery 6 November 2006 0600 UTC.

Table 1. Daily Precipitation and snow on ground at Flattop SNOTEL (elev. 6300 feet) and wind gusts at Logan Pass from 1-10 November 2006.

	Flattop Maximum Temp °F	Flattop Minimum Temp °F	Flattop Precipitation (Inches)	Flattop Snow on Ground (In)	Logan Pass Wind gust (mph)
Nov 1	24	-2	0	4	27
Nov 2	36	9	0.70	8	39
Nov 3	38	31	0.50	12	72
Nov 4	38	36	0.60	10	87
Nov 5	37	35	0.70	9	72
Nov 6	47	35	4.60	8	80
Nov 7	48	36	4.40	1	120
Nov 8	36	28	0	1	95
Nov 9	36	21	0	T	43
Nov 10	29	24	0.10	1	65



**Figure 6. Temperature and Precipitation trace at Flattop Mountain SNOTEL from 1-10 November 2006. The red line shows the freezing mark. Precipitation is in 3-hourly accumulations. Note how the temperature remained above freezing from the 3rd, into the early hours of the 8th. Strong westerly winds (Table 1) accompanied the period of heaviest precipitation on the 6th and 7th.**

Because the precipitation fell as rain, it moved into the drainages rapidly. Some high flow records and near records were set for November in some of the area drainages. At Lake Sherburne, on the east slopes in Glacier National Park, the lake level rose about 5.6 meters (18 feet) in three and one-half days (Fig. 8). On the west side, the North Fork of the Flathead River near Columbia Falls climbed nearly 1.8 meters (6 feet) in a day as the water rapidly filled area channels (Fig. 8). Figure 10 shows the near record flows at Swiftcurrent Creek that resulted.

High flows in November are uncommon. Normally, high flows occur in the spring, during the snowmelt runoff season that usually peaks in June. Figure 7 shows the high flows recorded in November 2006, as compared with historical measurements at Swiftcurrent Creek at Many Glacier. The flow at this location exceeded the previous record flow in November by over 1500 cubic feet per second (cfs). The mean flow recorded on 7 and 8 November 2006 was 2770 and 2330 cfs, respectively. The old November record was 1340 cfs set during a storm in 1999 in which 106 mm (4.2 inches) of rain fell at Many Glacier. At the North Fork of the Flathead River near Columbia Falls, a similar rare event occurred. The flow of 18,000 cfs on 8 November exceeded the previous November record of 13,000 cfs also set in 1999. Flows had exceeded 10,000 feet on only two other occasions. Again, high flows on the Flathead River are typically seen in the spring months.

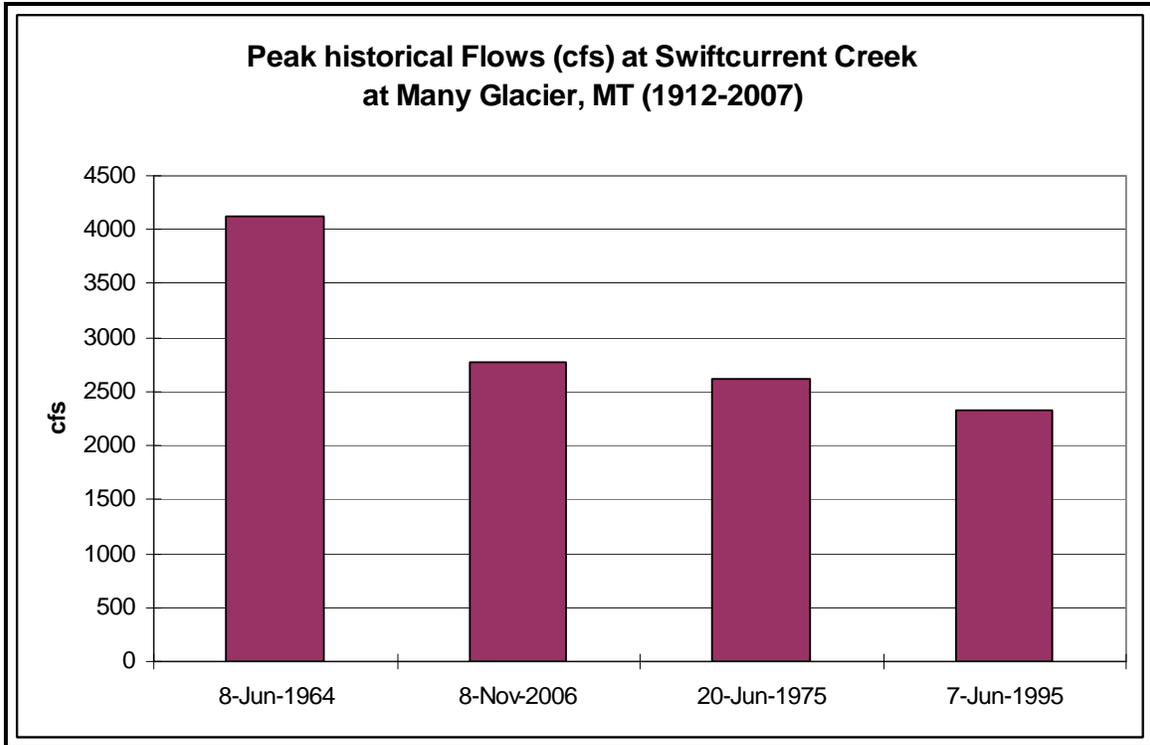


Figure 7. Historical peak flows at Swiftcurrent Creek at Many Glacier (courtesy USGS (United States Geological Survey)).

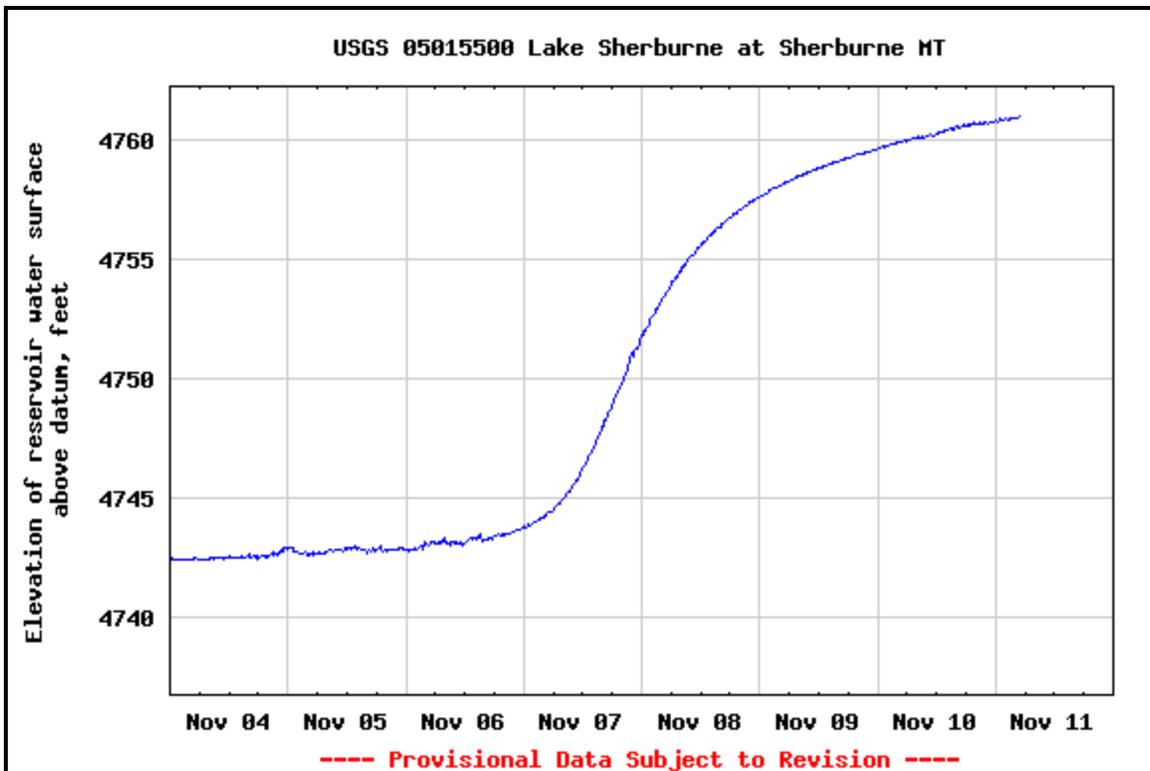


Figure 8. Lake level at Lake Sherburne, near Babb, MT on the St. Mary River drainage (courtesy USGS).

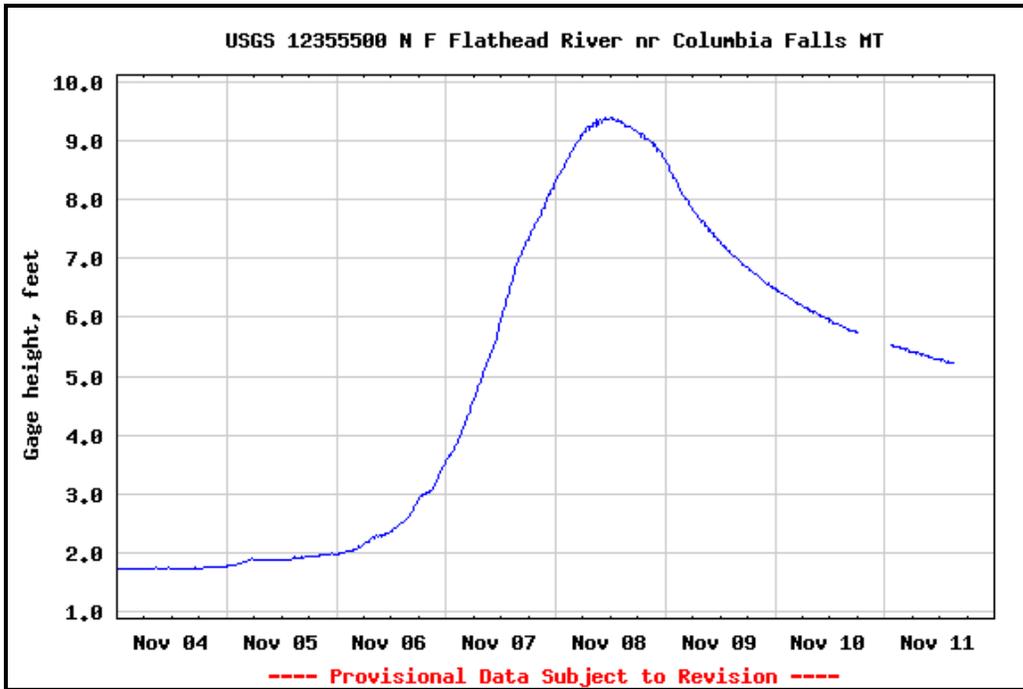


Figure 9. River stage values at North Fork Flathead River near Columbia Falls, MT. The mean daily flow on 8 November was 18,000 cfs, establishing a new daily record for November (courtesy USGS).

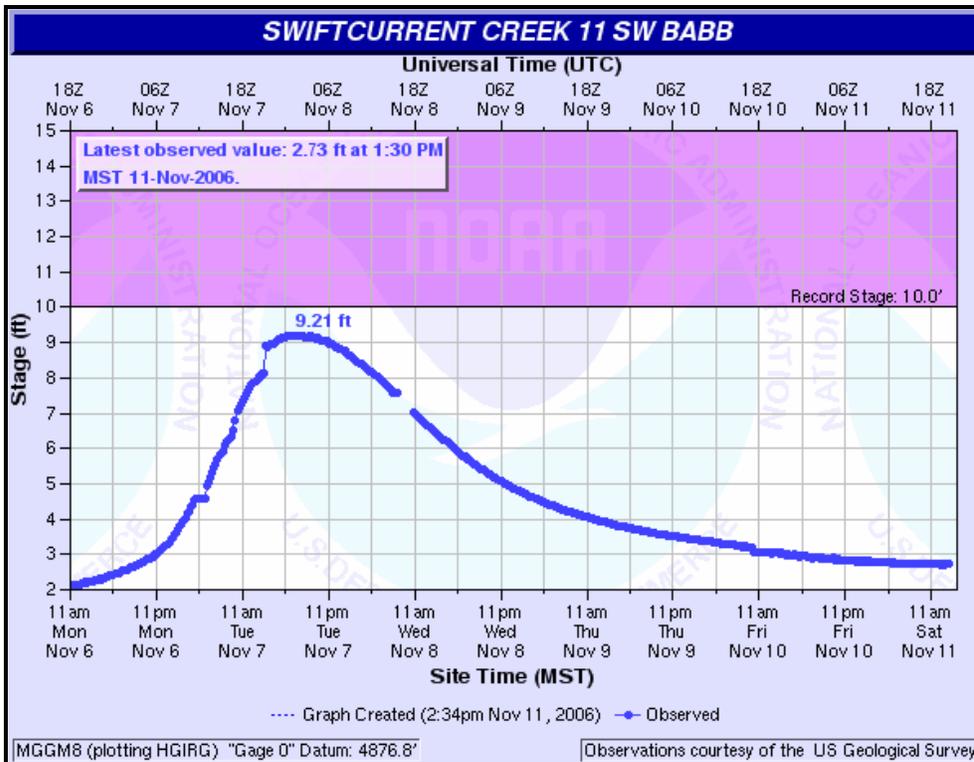


Figure 10. River stage values on Swiftcurrent Creek near Babb, MT. The 2.8m (9.21 foot) peak was near the record value of 3m (10 feet) (from the National Weather Service Advanced Hydrological Prediction System).

Major damage occurred to the infrastructure within Glacier National Park. Many roads, culverts and bridges were destroyed. More than a year later (in 2008), construction continued on rebuilding areas that were destroyed. Figure 11 shows the high water that affected the Many Glacier Hotel and flowed over the road that accesses the hotel. Water did enter the lower floor of the hotel to a depth of a little over 30 cm (one foot). Figure 12 shows the damage wrought to the roadbed by the floodwaters. Damage to the Going-to-the-Sun Road caused a road washout (Fig. 13). Because the damage occurred in November, the National Park Service and Federal Highway Administration worked closely to ensure that the Going-to-the-Sun road would be open and continue to be open for the 2007 tourist season (NPS 2007 and NPS 2007a).



**Figure 11. High water at Swiftcurrent Lake near Many Glacier Hotel. Water is running over the road accessing the hotel. The bridge submerged in the left-hand side of the photograph is the outlet to Swiftcurrent Lake, Swiftcurrent Creek (courtesy National Park Service).**



**Figure 12. Bridge over Swiftcurrent Creek after water levels subsided. Water continued to fill the channel under the bridge at a near capacity rate. Damage here is on the approach to the bridge (courtesy National Park Service).**



**Figure 13. Going to the Sun Road in Glacier National Park washout on 7 November 2006. This is on the east side below the tunnel east of Logan Pass. Note the center line of the road in the picture (courtesy National Park Service).**

## Model Evaluation

Overall, the GFS (Global Forecast System) model handled the event quite well. In the 96h forecast from 3 November 2006 (valid 1200 UTC 7 November), the GFS (Fig. 14) showed a plume of moisture that was akin to that shown on the AMSU and SSML imagery (Fig. 4). There was consistency from model run to model run can be seen in the 6 November 2006 12h forecast (Fig. 15). The plume of moisture had a little higher value on the later run, and the plume was a bit more displaced to the north. The relatively higher values pushed into western Montana and the Glacier National Park region. Both runs also indicated short-wave ripples in the vicinity during this time. This was also consistent with intermediate model runs. They too indicated small disturbances moving through the flow.

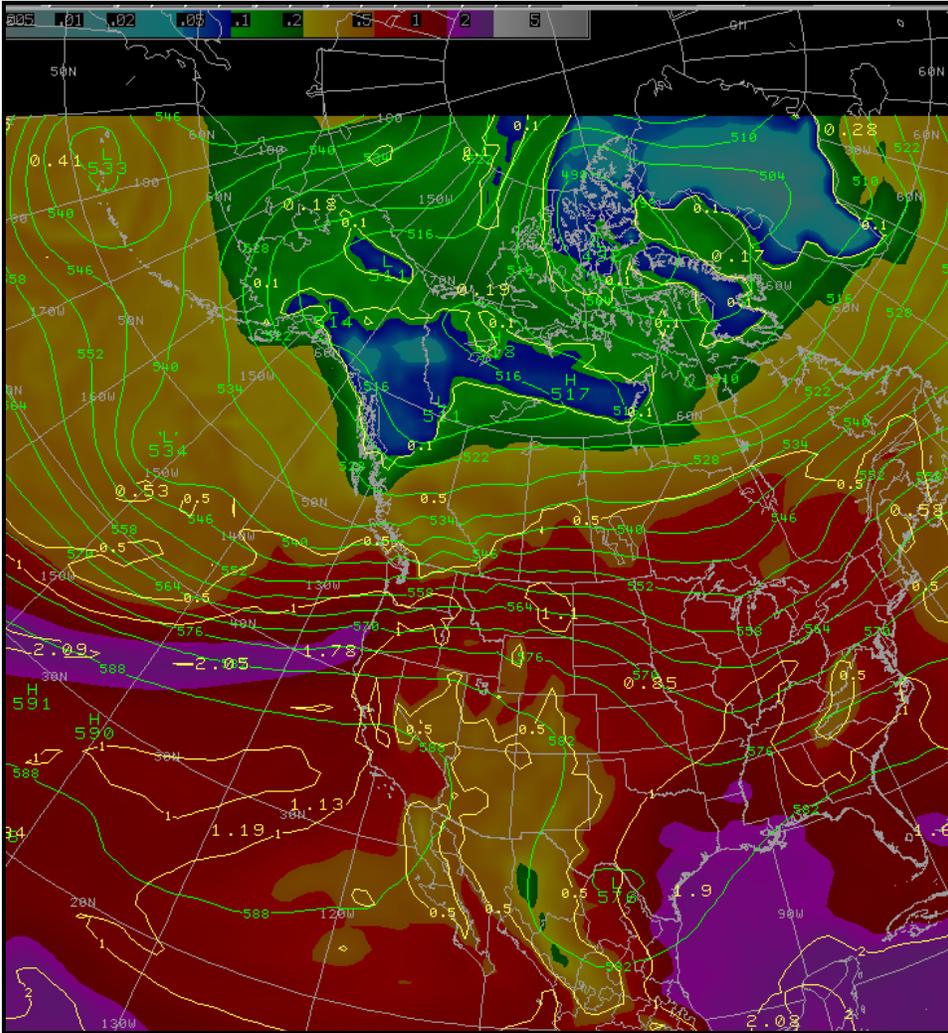
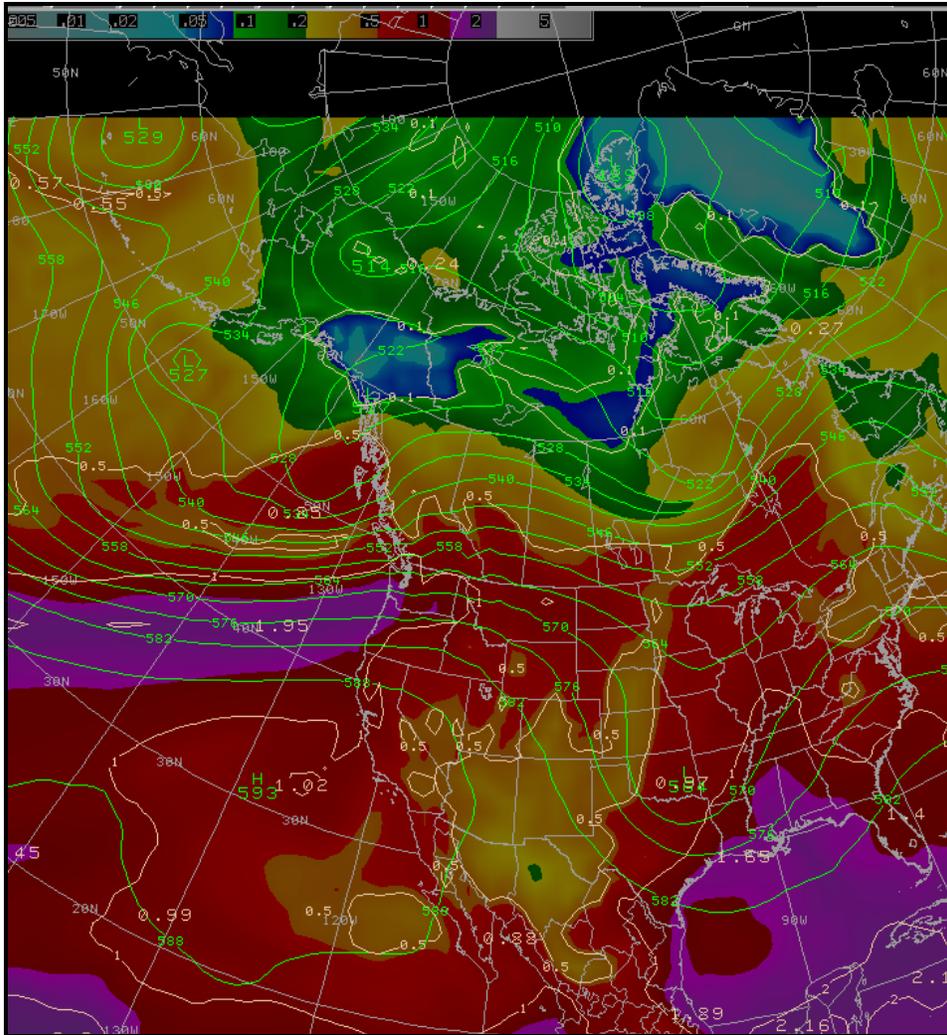


Figure 14. 96h GFS 500 mb height and precipitable water plot (color shaded) from the 3 November 2006 run. This forecast is valid at 1200 UTC 7 November 2006. The GFS showed a plume of moisture (purple) from the central Pacific Ocean, reaching the Idaho/Montana border with higher moisture values.



**Figure 15. 12h GFS 500 mb height and precipitable water plot (color shaded) from the November 2006 run. This forecast is valid at 0000 UTC 7 November 2006. The GFS continued to show a plume of moisture (purple) from the central Pacific Ocean. On this run, the moist plume was displaced a bit further north, still reaching Glacier National Park with higher values.**

During this stormy week, no major short wave weather systems moved through the area that would have been a major focus to enhancing the heavy precipitation. In this case, it appeared that the strong moisture flow from tropical sources interacted with minor disturbances in the flow. Topographic upslope, strong upward vertical velocities (approaching 20 microbars per second) (Fig. 16) and ageostrophic winds (Fig. 17) seemed to be the larger contributors to the heavy precipitation. A strong upper jet existed over the area. In Figure 17, the cross section across northwest Montana, shows the strong thermally direct circulation in the right entrance region of the jet in the area, which produced persistent upward vertically motions as from the ageostrophic wind.

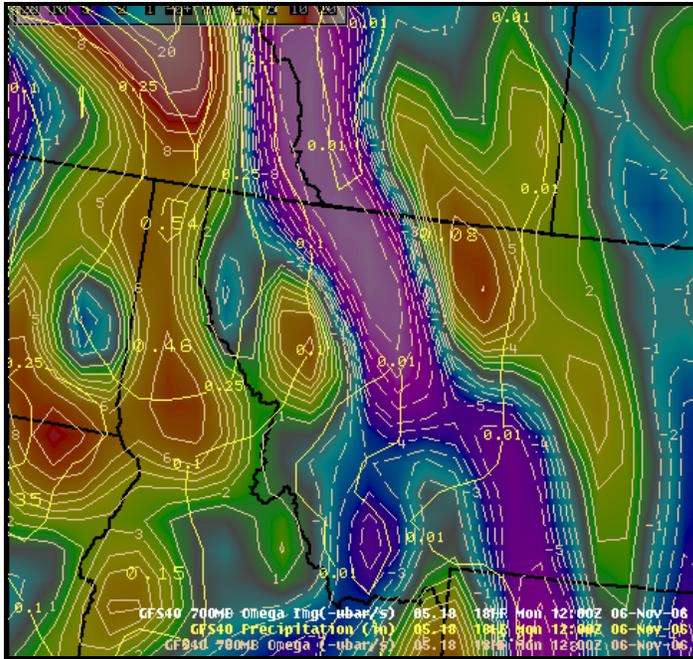


Figure 16. GFS model 700 mb vertical velocity field valid 1200 UTC 6 November 2006. Vertical velocities approached 20 microbars per second near Glacier National Park on the windward side of the Continental Divide.

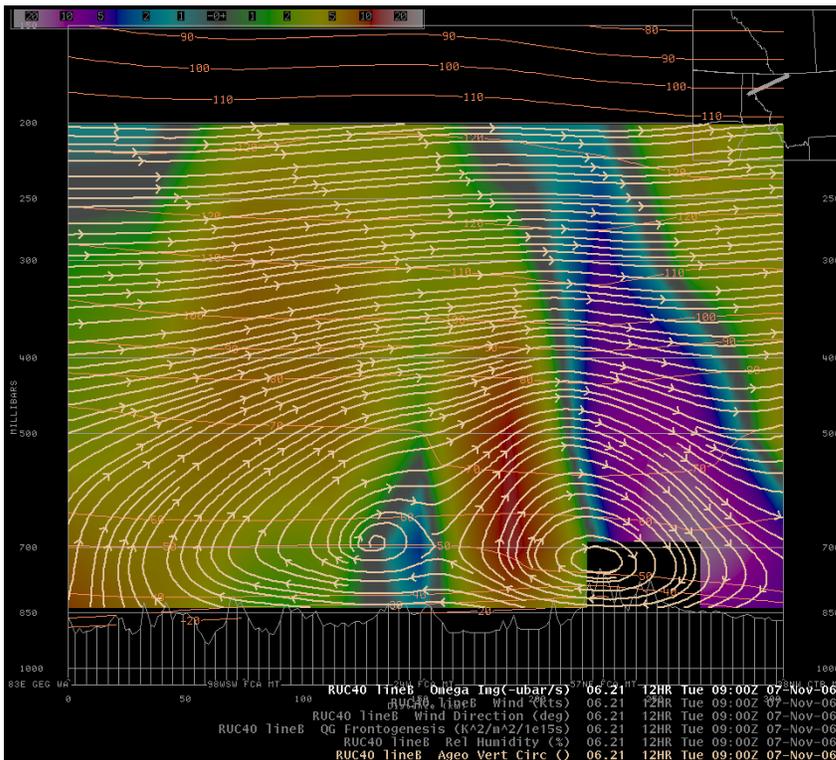


Figure 17. Rapid Update Cycle 12h forecast vertical velocity and ageostrophic winds valid at 0900 UTC 7 November 2006. The cross section extends from northern Idaho, through Glacier National Park, to the plains just east of the park in Montana.

The NAM (North American Mesoscale) and GFS models both forecast relatively high precipitation amounts for the heaviest precipitation period, but qualitatively both under forecast the magnitude averaged over the area. Figure 18 depicts the NAM forecast of 48h precipitation for northwestern Montana. The higher amount of 135 mm (5.31 inches) on the west side of the divide near Glacier National Park, and other bull's-eyes of precipitation were forecast along the Idaho-Montana border. These were related to many of the features noted earlier, and aligned with regions of higher topography (Fig. 2). The GFS model depiction of 48h precipitation was very close to the NAM forecast.

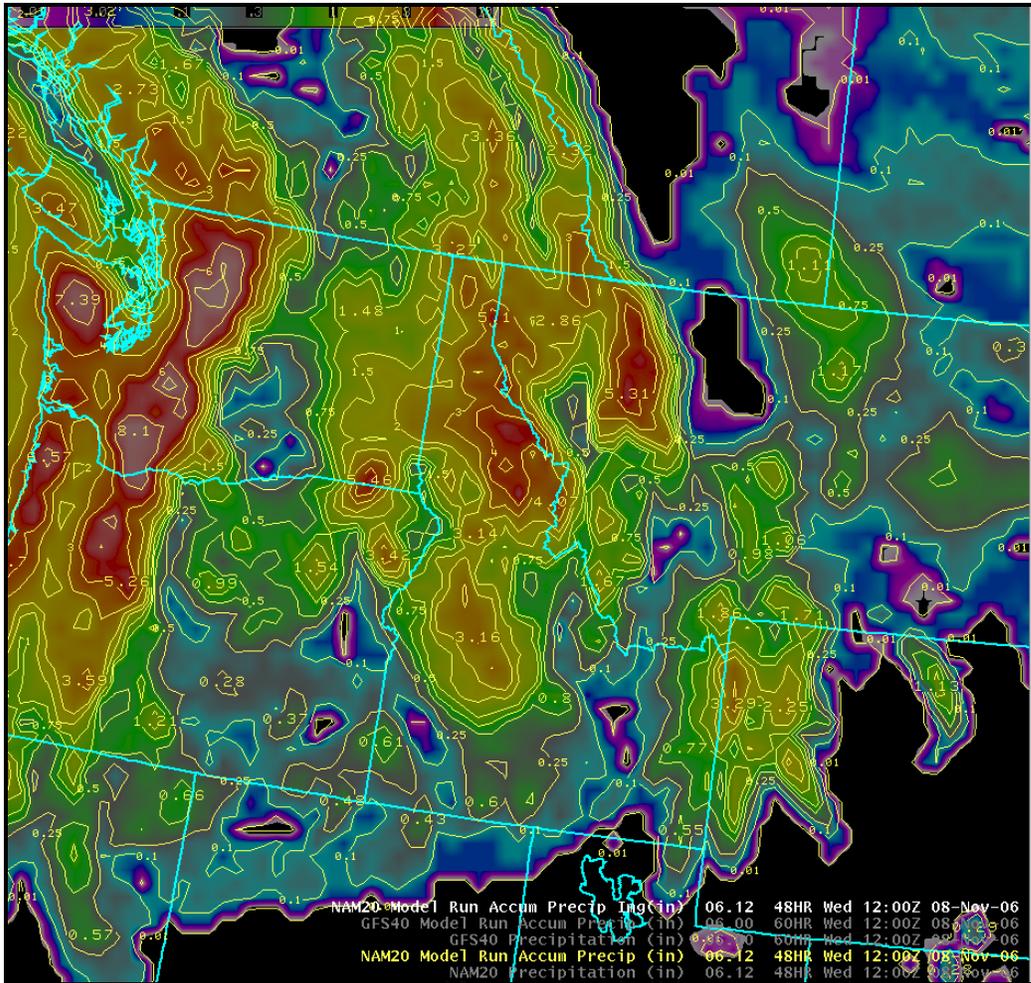


Figure 18. NAM 48h model accumulated precipitation ending at 1200 UTC 8 November 2006. This is from the 1200 UTC 6 November 2006 model run.

## Conclusion

In general, the heavy precipitation over northwest Montana was forecast well in advance by the GFS, and handled well in the shorter-term by the NAM. Both models underplayed the magnitude of the event. The GFS forecasted large amounts of moisture moved northeastward by the subtropical jet stream. As this

moisture impinged upon the complex terrain of northwest Montana, local topography played a large role in focusing higher precipitation amounts. The warmth of the air mass during this event produced large amounts of rain, when snow would have been the climatological normal in early November. The mesoscale dynamics associated with the topography and ageostrophic circulations associated with the jet-level winds served to concentrate higher amounts of precipitation along favorable windward upslope mountain ridges. Strong winds blew the precipitation farther east across the continental divide than is typically noted in lighter wind regimes. The merging of the favorable ingredients served to produce one of the heaviest November precipitation events over northwest Montana of record, and cause some of the worst flood-related damage to Glacier National Park and vicinity since 1964.

### **Acknowledgements**

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