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Locations of the International Airports of the Pearl River Delta

This Landsat-7 satellite image, acquired on 2004-02-14, shows the locations of the four international airports of the Pearl River Delta in South China. (Close-up views on the back cover)

The Earth From Afar: Image Review

Editor: Paul R. Baumann
Department of Geography
State University of New York at Oneonta
Milne Library 317
Oneonta, NY 13820
U.S.A.

The Big Melt Down: The Columbia Icefield

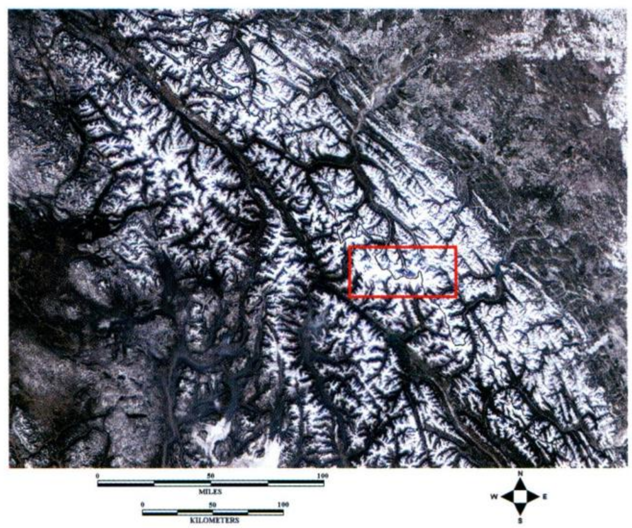
Paul R. Baumann
Department of Geography
State University of New York
College at Oneonta
Oneonta, NY 13820 U.S.A.

Introduction

Straddling the boundary between the Canadian provinces of Alberta and British Columbia, the Columbia Icefield is the largest ice mass in North America, south of the Arctic Circle. Situated in the Canadian Rockies, this ice field covers an area of 130 square miles (365 sq. km.) and has a maximum depth of 1,200 feet (365 m), the height of the Empire State Building in New York City. The general location map shows the Canadian Rockies in mid-winter with the Columbia Icefield highlighted. The average elevation of the ice field is about 10,000 feet (3000 m). It occupies a high, flat-lying plateau in the form of a huge massif. Its highest points are Mount Columbia at 12,284 feet (3745 m) and Mount Athabasca at 11,452 feet (3,491 m). The average snowfall across the ice field is 23 feet (7 m) per year.

Three different types of large ice masses exist, namely *ice sheets*, *ice caps*, and *ice fields*. Ice sheets are associated with continental glaciers and are the largest of the three types of ice masses. Today, they are found in Greenland and Antarctica. Ice caps and ice fields relate more to mountain locations. Ice caps are more circular in area and form more of a dome shape. On the other hand, ice fields are elongated in pattern and wrap around mountains leaving only their peaks showing. Such peaks are called *nunatak*. All three of these ice masses have *outlet glaciers* around their edges that drain them to provide fresh water.

Six large outlet glaciers flow from the Columbia IceField. They are the Athabasca, Saskatchewan, Dome, Columbia, Castleguard and Stutfield Glaciers. Through these glaciers fresh water flows from the Columbia Icefield into three different oceans namely the Atlantic, the Pacific and the Arctic. This situation is referred to as the "hydrographic apex of North America," basically the center of water distribution in North America. Only one other similar divide exists and it is in northern Siberia. This image review centers on the melt back of two of the outlet glaciers on the eastern edge of the Columbia Icefield. They are the Athabasca and Saskatchewan glaciers. Figure 1-A is a topographic map showing the eastern half of the Columbia Icefield with the Athabasca and Saskatchewan glaciers.



Map MODIS image taken March 4, 2002. Study area highlighted in red. Image Credit: Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC

Mountain Glaciers

From their source to their terminus, glaciers can be divided into two zones, the zone of accumulation, and the zone of ablation or melting. Where a glacier develops near the edge of an ice field, it receives great accumulations of fresh snow. At this point the glacier appears clean and a bright white in color. The elevation is high enough and cool enough to maintain the snow throughout the year. This snow compacts as ice, which becomes part of the glacier as it moves down slope. A glacier is compacted ice that is moving. Fresh snow and ice also enter the glacier directly from the ice field.

As the glacier flows farther away from the ice field and downhill, it becomes dirty and rougher in appearance. It is entering the zone of melting. The fresh snow is melting and exposing the glacial ice, which contains various unsorted materials. Meltwater streams appear on the surface especially during the summer. When a glacier melts more snow and ice than it receives, it begins to recede. Most glaciers in the Rockies are presently receding.

When a glacier recedes, large amounts of debris that has been held and carried by the ice is released and deposited on the landscape to form new landforms. This debris is referred to as *till*. Till is unsorted material. In other words, materials of varying sizes and shapes are mixed together when deposited. In contrast, sediment carried by running water is generally sorted with the larger materials being deposited first followed by smaller materials. Till deposited as linear ridges forms landforms called *moraines*. A glacier carries a tremendous amount of till near its terminus or front edge. When the glacier stops, some of this till is deposited to form an *end moraine*. If the glacier advances over the end moraine, the moraine might be destroyed. The end moraine that represents the farthest extension of the glacier is the *terminal moraine*. In the retreating process, a glacier also might temporarily stop and form a *recessional moraine*. As a glacier moves down a valley, the friction created by the valley sides forces deposition along the edge of the glacier. These depositions are referred as *lateral moraines*. If a glacier is receding, lateral moraines provide evidence of how far the glacier has retreated. Figures 2 and 3 show Athabasca and Dome glaciers, respectively. A large lateral moraine can be observed on the right side of Figure 2. Also, a large lateral moraine can be seen cutting diagonally across the lower half of Figure 3. These lateral moraines clearly illustrate where these glaciers were previously located.

When two glaciers flow together a moraine might develop between them. This type of moraine is known as a *medial moraine*. The Saskatchewan glacier has a tributary glacier feeding into it with a medial moraine separating them. The brown dot pattern cutting the length of the Saskatchewan glacier in Figure 1-A illustrates the medial moraine. This topographic map was made in 1960 and the tributary and Saskatchewan glaciers are the same length. Figure 4 shows the Saskatchewan glacier in 2001 and the tributary glacier has retreated substantially more than the main glacier. The medial moraine can be seen between the two glaciers. Figure 1-F is an annotated satellite view that provides a pattern perspective of some of the features previously discussed.

Climatic Change

Over time the Earth's climate has varied between cold and warm periods. Obviously, ice masses and their respective outlet glaciers expanded during cold periods and melted back during warm periods. The expansion/contraction of ice masses and the movement of glaciers have marched over the Canadian Rockies for at least a quarter of a million years. In fact, the first major ice advancement in this region may have occurred as long as 1.9 million years ago. The Great Glaciation period started 240,000 years ago and lasted until about 128,000 years ago. This period is also called the Illinoian Glaciation. Huge outlet glaciers flowed from the Canadian Rockies eastward into the central plains of present day Canada and northern United States. Their flow eastward continued until they merged with the large outlet glaciers that were rapidly expanding westward from the continental ice sheet centered over Hudson Bay. Table 1 outlines some of the major advancement and retreats of glaciers within the Canadian Rockies. Various theories as to why these glaciers started and ended have been put forth but no absolute cause has been identified. At present the Earth appears to be in a

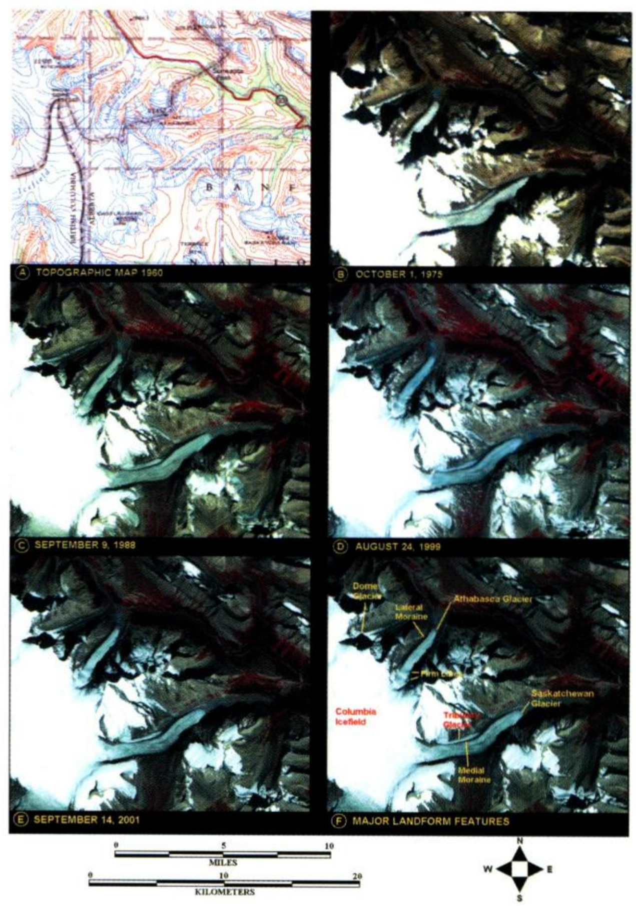


Figure 1 A-F. A series of Landsat images with a topographic map showing the melt back of the glaciers from the Columbia Icefield.

Figure 2 Athabasca Glacier with Columbia Icefield in the background and lateral moraine on the right side indicating area previously covered by the glacier.

Table 1 Timetable of Canadian Rockies Glacial Periods

Name	Began	Ended
Cavell Advance (Little Ice Age)	1200 AD	1900 AD
Warm Period	8,700 BP	4,000-5,000 BP
Crowfoot Advance	After 11,000 BP	Before 9,000 BP
Late Wisconsinan Advance	20,000 BP	11,000 BP
Early Wisconsinan Advance	75,000 BP	64,000 BP
Illinoian (Great Glaciation)	240,000 BP	128,000 BP

http://www.mountainnature.com/Geology/Glaciers.htm

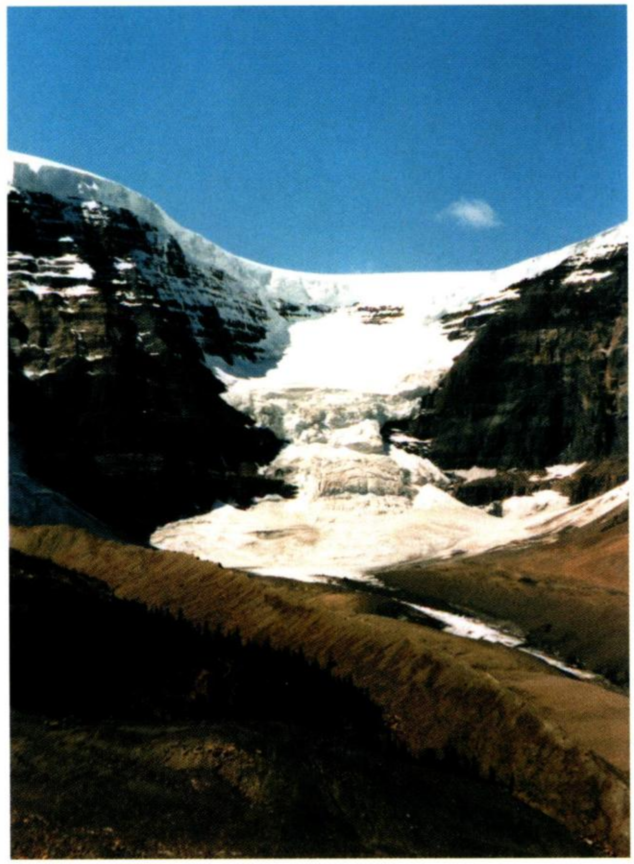


Figure 3 Dome Glacier with Columbia Icefield in the background and large lateral moraine in foreground.

warming period due to ice masses, such as the Columbia Icefield, and their outlet glaciers melting back. Much has been written about this melt back being caused or execrated by various human activities, which may or may not be the case. What is known is that the Canadian Rockies have experienced several ice advancements and retreats and the present period of melt back covers a relatively short time span when compared to the last quarter of a million years.

Athabasca and Saskatchewan Glaciers

The Athabasca and Saskatchewan glaciers have been researched extensively since the early 1950s. The Athabasca Glacier presently covers an area of about 11.5 square miles (30 square km). This glacier can be easily observed from Canadian Highway 93 and specialized buses take tourists out onto the glacier from the Icefield Centre. Investigations of its terminal, recessional and lateral moraines have recorded the movement of the glacier over the past few centuries. The glacier has advanced and retreated several times during this period. Historical records, maps, and photographs dating back to 1897 show that over the last 125 years the glacier has retreated about .93 miles (1.5 km). Tree-ring studies indicate that around 1715 the glacier had advanced more than any time in at least the preceding 350 years. The 1715 advancement would have the glacier's terminus spreading across Highway 93 and reaching the Icefield Centre. Figure 2 was taken with a zoom lens from the Centre, which is located on the other side of the highway.

After the 1715 advancement, the glacier receded. Then again, with the beginning of the 19th century it advanced reaching by about 1850 an extension almost equal to the 1715 advancement. Except for brief standstills the glacier from the mid-19th to the late 20th century has been retreating. Indications suggest that recent reduction in snow melt off might produce an advancement in the 21st century.

The Saskatchewan Glacier is the largest on the Columbia Icefield. Its present coverage is about 23 square miles (60 square km) and measures as deep as 1,450 feet (442 m). Unlike the Athabasca Glacier, it cannot be viewed from the highway. However, its accumulation, flow, and ablation (loss) have been similar to Athabasca and the other outlet glaciers from the Columbia Icefield.

Observations from Landsat

Using satellite imagery it is quite easy to recognize the recent melt back of the Athabasca and Saskatchewan glaciers. Figure 1-B to 1-E compose a grouping of four Landsat images dating from 1975 to 2001 and a topographic map

Figure 4 Saskatchewan Glacier and tributary glacier with medial moraine between the two glaciers. Photograph taken and provided by Mr. Ben Tomhave.

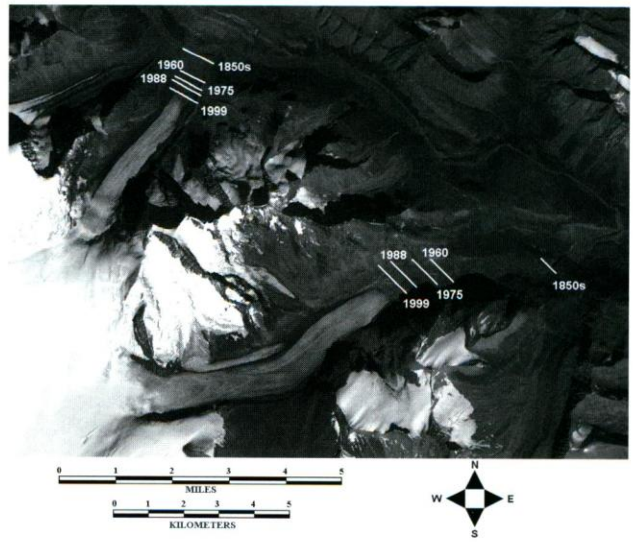


Figure 5 Band 8 of the 2001 ETM image with the terminus points at different dates indicated for the Athabasca and Saskatchewan Glaciers.

from 1960 that show the Columbia Icefield and Athabasca, Saskatchewan, and Dome Glaciers. Figure 1-F identifies these geographic features. Landsat 7 using its Enhanced Thematic Mapper (ETM) scanner recorded the 1999 and 2001 images. Landsat 5 took the 1988 image with its Thematic Mapper (TM) scanner and Landsat 2 with its Multispectral Scanner (MSS) recorded the 1975 image. A near infrared and the red and green visible bands were used to create these false color composites. The picture element size on the TM and ETM images was 27.5 meters by 27.5 meters. The picture element size for the 1975 MSS image was 55 meters by 55 meters. Due to its lower resolution the 1975 image was not as sharp as the other images but it was still possible to detect the terminus points for the two glaciers and the various morainal landforms associated with them.

The white color displayed in the composites shows the Columbia Icefield. The blue color identifies the glaciers as they flow out of the ice field in the shape of large tongues. The red reflects mainly evergreen forests. The grey-brown represents bare land. Finally, the black indicates shadow conditions from mountain peaks. Shadows extend across large sections of the glaciers in the 1975 image when the sun was at a lower angle than with the August and September images. All four images are from the fall period of the year when the greatest amount of summer melt back of the glaciers has already occurred.

Using landmarks that are constant on all four images it is possible to determine the terminus points for Athabasca and Saskatchewan glaciers at the various dates. Figure 5 is from Band 8 of the 2001 ETM image. Band 8 provides a higher resolution than the other bands. Its resolution is 15 meters by 15 meters. The 1999, 1988, and 1975 terminus points for the two glaciers are indicated. In addition, the 1960 terminus points from the topographic map are provided. Finally, using the various morainal landforms shown on the images, the terminus points associated with the last major advancement of the glaciers can be detected. The last major advancement occurred in the 1850s.

From 1960 to 2001 the two glaciers have been retreating at a rather constant rate. However, the rate for Saskatchewan Glacier appears greater than the rate for Athabasca Glacier. Athabasca Glacier is melting faster at the present time then it has in the past 40 years. This melt back is due mainly to warmer weather and more surface dirt that absorbs summer heat. If these glaciers would disappear, fresh water availability in several sections of North America would become a major problem. In the hot, dry summer of 1998, the Athabasca Glacier was the only source of fresh water that kept several large river systems on the Canadian Prairie flowing. Research indicates that the glaciers of the Columbia Icefield could be gone within the next 50 to 100 years, and maybe sooner, if the Earth's temperature continues to increase.