Year 12 Independent research for summer 2016

Build a glossary of key terms associated with glaciers and cold environments. Key terms should include:

Past climate change: Milankovitch Cycles; Pleistocene; Holocene; interglacial

Cold environments: Cryosphere; ice sheets; ice caps; valley glaciers; polar (cold based) glaciers; temperate (alpine/warm-based) glaciers; ice fields

Mass balance: mass balance; ablation; accumulation; sublimation; calving

Glacial processes: weathering; freeze-thaw weathering; erosion; abrasion; plucking; quarrying; crushing; basal melting; entrainment; transport; deposition;

Glacial landforms: cwm/corrie/cirque; arêtes; pyramidal peaks; glacial trough; truncated spurs; hanging valleys; ribbon lakes.

Use the resources on iPupil and the following websites for your research:

http://www.physicalgeography.net/glossary.html

http://www.acegeography.com/cold-environments.html

http://www.coolgeography.co.uk/A-level/AQA/Year%2012/Cold%20environs/Cold%20envs%20main.htm

http://www.geography.learnontheinternet.co.uk/keywords.html

The Athabasca Glacier

Build up a case study of the Athabasca glacier in Canada. Use Geofile 517 which is in 'General reference documents' in the 'Cold Environments' section on iPupil. Use the following pointers to help you develop your case study:

- Where is the Athabasca glacier located? Include maps to illustrate location.
- What *type* of glacier is it?
- How long and deep is the glacier and what area does it cover?
- How fast is the glacier moving – at the icefall and at the snout?
- **Briefly summarise** the past mass balance of the glacier.
- Show the mass balance of the glacier for 1976 in an equation using the data provided.
- What types of moraine has the glacier deposited? Give details.
- Under what conditions were the recessional moraines deposited? Think about the movement of the glacier.
- Search Google Maps for a **satellite image** of the Athabasca glacier. Print off a copy of it and highlight the following on the photograph using figure 4 (map) to help:
    - Direction of ice movement
    - The Dome glacier
    - Sunwapta Lake (a pro-glacial meltwater lake)
    - The maximum extent of ice
    - Icefall
    - Sunwapta Valley
    - The Colombia Icefield
    - Location of moraines
- When is the Sunwapta Lake estimated to be completely filled and why?
- At what rate is the Athabasca glacier retreating?
- When do glaciologists predict that it will completely disappear?
- What will the consequences be is the Athabasca glacier disappears altogether?

Geofile Online
APRIL 2006
517

NEIL PUNNETT

THE ATHABASCA GLACIER – A GLACIER IN THE CANADIAN ROCKIES

Valley glaciers can be classified by their source. Some have their origin in cirques, which are large armchair-shaped hollows carved out of mountainsides. Many famous examples of such cirques are found in the British Isles, including Red Tarn on Helvellyn in the Lake District and Cwm Idwal on Snowdon in North Wales. Other valley glaciers move down from vast ice-fields which cover parts of mountainous areas; such valley glaciers are also termed outlet glaciers. This **Geofile** is a detailed case study of one such outlet glacier.

Figure 1: Photograph of the Athabasca Glacier from the Icefields Parkway

© Neil Punnett

The Columbia icefield

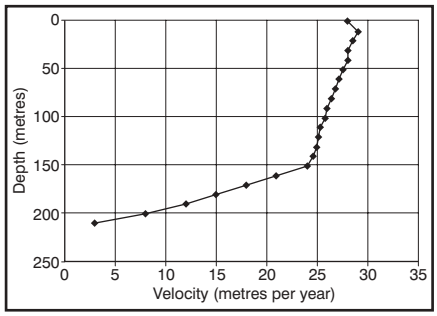
The Athabasca Glacier is in Jasper National Park in the Rocky Mountains of Alberta in western Canada. It is an outlet glacier from the Columbia Icefield, the largest area of ice and snow in the Rockies. The Columbia icefield covers an area of nearly 350 km^2, a similar size to the Isle of Wight. Fifteen thousand years ago, the icefield was part of a vast ice sheet which stretched from the Rockies to the Pacific Coast, covering Canada's western edge so thickly that only the tips of the highest mountains poked above the frozen wastes, as isolated nunataks. Today the icefield is surrounded by 11 of the Rockies' highest peaks, including Mt Columbia which rises to 3750 m, Mt Kitchener 3505 m and Mt Athabasca 3493 m. The average altitude of the icefield is 3000 m; it is fed by about 10 m of snowfall annually. In places the ice is over 900 m deep.

The Athabasca Glacier

The Athabasca Glacier itself flows north-eastwards from the icefield towards the valley of the Sunwapta river. The glacier is 6 km long and it covers an area of over 6 km^2. Its depth varies from 90 to 350 m. The glacier flows out from the icefield in a dramatic icefall at an elevation of 2700 m through a clearly U-shaped glacial trough to a point slightly below 2000 m, where its snout lies above the valley of the Sunwapta River.

The Athabasca Glacier is flowing at 125 m per year at the icefall, but only 25 m per year at the snout. In cross-section (Figure 2), the ice can be seen to be moving at differing rates with depth – at up to 30 m per year near to the surface, but clearly decreasing with depth as the frictional effects of the bedrock over which it is moving become greater. At the base the rate of movement is less than one-tenth that at the surface.

Figure 2: Velocity profile of the lower Athabasca Glacier

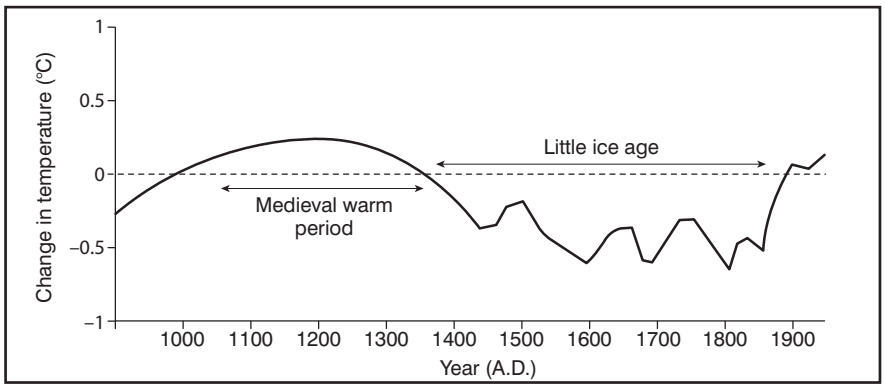


Advance and retreat

The glacier snout has retreated and advanced since the height of the Ice Age 15,000 years ago. By about AD1300 the glacier had shrunk to only about 3 km long. The global climate was cooling, however (Figure 3) and the glacier started to re-advance. It surged down the valley, overwhelming a forest of spruce and fir that had grown up during the earlier period of relative warmth. The effects of this most recent advance are clearly evident in the high lateral moraines along the valley walls. By 1840, the Athabasca Glacier stretched far down the Sunwapta River Valley (Figure 4). In the latter half of the 19th century, the climate started to become warmer again and the ice slowly began to melt, leaving a large terminal moraine to mark its farthest extent. Since then, it has receded by about 1500 m. The rate of retreat varies from year to year. When the retreat of the glacier's snout halts for a while, recessional moraines are formed. There are several recessional moraines running across the valley between the current position of the snout and the upper car park. The retreating glacier has exposed extensive areas of smoothed and striated bedrock.

Because the rate of ablation has generally exceeded the rate of accumulation in the recent past, as a whole the glacier has shrunk substantially and the position of the snout is retreating up the valley. The rate of retreat varies from year to year. In 1976, Parks Canada judged that the middle of the glacier flowed forward at least 35 m, but melted back about 38 m, receding a total of 3 m. In some years, the total meltback can be as much as 38 m, or as little as none at all (Figure 5).

Figure 3: Global temperatures since AD 1000



It is a fascinating experience to walk up to the snout of the glacier, passing markers placed by the Parks Canada agency showing where the snout was in past years. The recessional moraines serve as natural markers of this retreat. In addition, the glacier's lateral moraines now stand 150 m or more above the ice surface, showing how much melting has occurred in recent decades. An indication of the rate of thinning of the ice is given in Figure 6, which shows the results of depth measurements taken 12 years apart, in 1966 and 1978 on the lower part of the glacier. The greatest difference recorded was 25 m at an altitude of 2202 m above sea level; i.e. at that point the glacier had lost 2 m of ice thickness per year during that period.

Figure 4 shows that the Athabasca Glacier actually joined with the neighbouring Dome Glacier at the maximum extent of its advance in the mid-19th century. The earliest photograph of the glacier dates from 1906 and was located by Brian Luckman and a team of geographers from the University of Western Ontario. Figure 7 shows sketches based on that photograph, and one taken from the same spot in 2004. In addition to the retreat of the snout, the glacier appears to be over 100 m less thick in 2004 than it was in 1906. Another useful photograph is an aerial

Figure 4: Map of the Athabasca Glacier

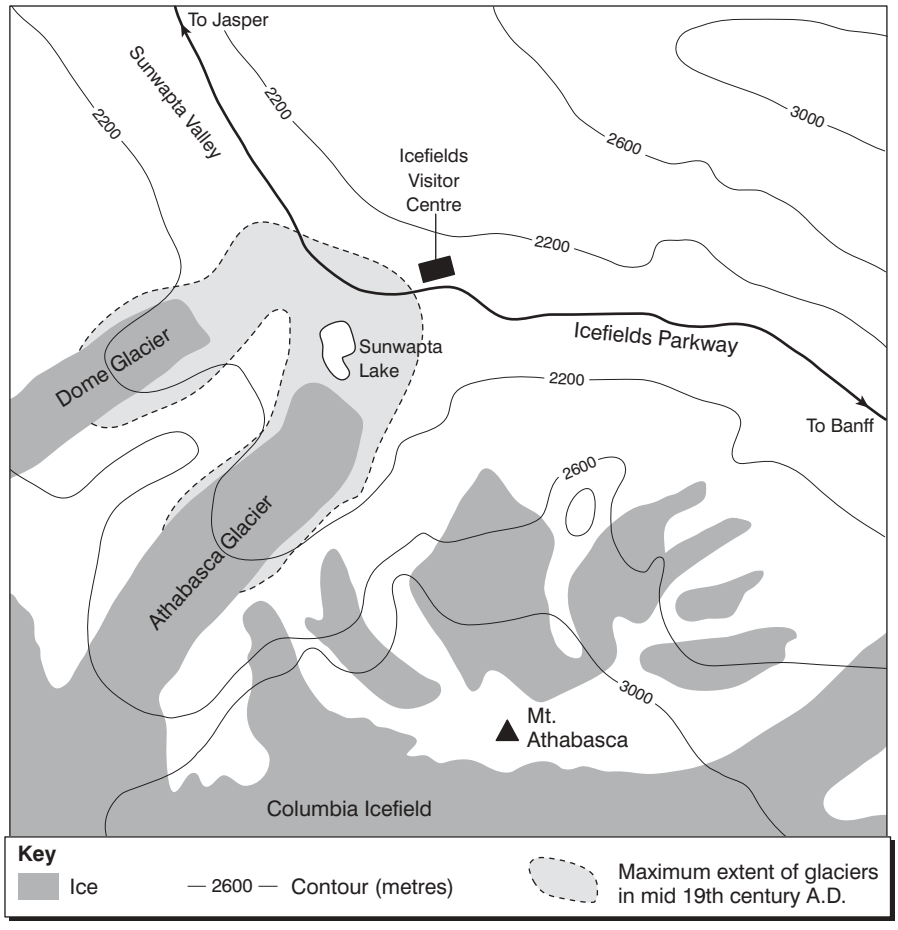
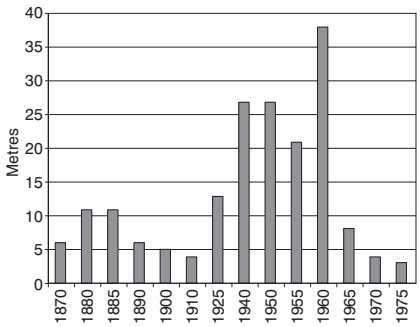


Figure 5: Annual recession of the snout of the Athabasca glacier 1870–1975



view taken in 1939, which can be found at the following website address: http://airphotos.nrcan.gc.ca/photos101/images/a6619_043.jpg. This clearly shows the snout of the Athabasca glacier very close to the highway.

Note the appearance of the lake in the 2004 sketch, which began forming in 1940; Sunwapta Lake is a pro-glacial meltwater lake. Meltwater from the Athabasca Glacier flows directly into the lake and then exits to the Sunwapta River via a single outlet. The lake thus acts as a natural sediment trap and is likely to be a short-lived feature, since it is being rapidly filled in by sediment. Fieldwork conducted by Challies in 2000, including depth soundings, led him to estimate that approximately 20,000 m^3 per year of sediment was deposited in Sunwapta Lake from 1974 to 2000. If sedimentation continues at this pace, Sunwapta Lake will be completely filled in by 2015.

Tourism

The Athabasca Glacier is probably the most photographed glacier in the world because its snout lies close to the busy Icefields Parkway road (Highway

Figure 6: Depth measurements on the Lower Athabasca Glacier in 1966 and 1978

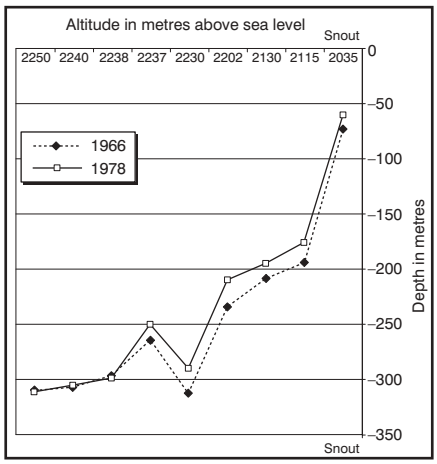
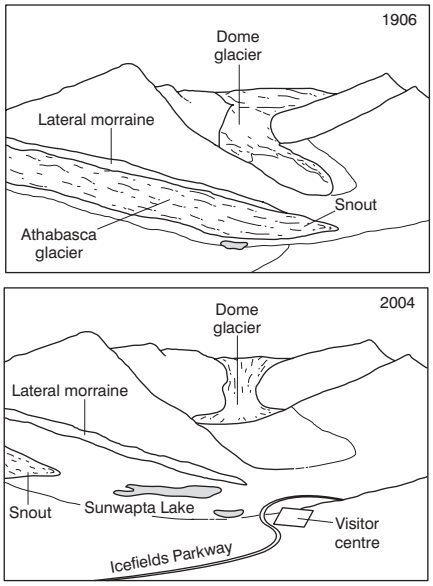


Figure 7: Sketches based on the first known photograph of the Athabasca Glacier taken in 1906 and one taken from the same spot in 2004



Credit: Brian Luckman

93) linking the towns of Banff and Jasper. More than 10,000 people pass this spot every day in the summer. Most will stop at the Columbia Icefield Centre, an impressive £3 million complex opened in 1996, replacing a smaller lodge dating from 1931. The Icefield Centre has extensive car parking for 730 cars and 100 buses and welcomes over one million visitors each year. Inside the centre, models and audio-visual displays explain the formation and movement of the glacier. The Centre also includes a restaurant and café, and hotel rooms for overnight stays. On busy days, more than 6,000 people will take a trip on one of the snocoaches – specially designed 6-wheel-drive vehicles with huge balloon tyres which take them out onto the glacier where they can disembark and walk on the glacier's surface. Experienced guides also offer hikes across the glacier and up the icefall onto the icefield above. Helicopters fly wealthier tourists directly up to the icefield.

Concern has been expressed at the effects on the area of millions of trampling feet, especially on the newly exposed land at the glacier's snout. The Icefield Centre, its extensive car parks, the snocoach road and base, the noisy helicopters and road vehicles are all obtrusive in this frozen landscape. However, the benefits of concentrating the tourists at one point probably outweigh the disadvantages.

The Athabasca Glacier has been designated a World Heritage Site by the United Nations, and it attracts over one million visitors each year.

The future?

Research suggests that the Athabasca Glacier is shrinking by 30 per cent every 100 years and, if the shrinkage continues at the same rate, the glacier could be gone in less than 300 years. Other glaciers in the area could disappear in less than 50 years and scientists warn the melt could speed up if the Earth's temperatures continue to climb. If the glaciers in the Columbia icefield disappear, so will a critical water supply for western Canada. The Athabasca Glacier feeds several large prairie water systems. In a hot dry summer like that of 1998, the glacier meltwater is the only thing that keeps the rivers flowing.

The shrinking of these glaciers has been used by some as evidence of the increasing effect on the world's climate of man-made greenhouse gas emissions. There is little doubt that the average global temperature is increasing – Figure 8 shows readings from meteorological instruments since 1856 – but whilst the majority of scientists (and almost all the news media) believe that this is at least partly due to human actions, there is no consensus. A significant minority of scientists state that the global warming observed since the mid-19th century is simply a natural phenomenon. Two such scientists holding the minority view are Sallie Baliunas and Willie Soon from the Harvard-Smithsonian Center for Astrophysics. They state: 'the Medieval Warm Period and the Little Ice Age were real. They were also widespread over the globe. The twentieth century is not the least bit climatically unusual.'

A longer-term graph of reconstructed temperatures since AD 0 (Figure 9) shows that global warming has occurred before: between about AD 700 and AD 1100 the mean global temperature rose by 0.6° C to reach similar average temperatures to the present, followed by a slow decline after AD 1200. The period between AD 1000 and AD 1300 has been called the medieval warm period.

Once thought of as a purely North Atlantic region phenomenon, recently evidence in support of this medieval warm period has been discovered in several places around the world:

- Study of the cultivation of subtropical citrus trees and herbs shows that North East China had a temperature about 1°C higher than today between AD 1100 and 1200.
- The temperature in the interior of South Africa was higher by 3°C during the same period, based on measurements of carbon and oxygen isotopes in stalagmites.
- The surface temperature of the Sargasso Sea in the North Atlantic exhibited a 1°C rise 1,000 years ago and 1°C decrease about 400 years ago, as shown by the level of the oxygen isotope in seafloor sediments.
- Borehole measurements into the Greenland ice sheet indicate a temperature 1°C higher around AD 1000 and 1°C cooler between AD 1500 and 1850.
- In western Europe, documentary evidence describes the moderation of harsh winters from AD 900 to 1300 relative to those from 1300 to 1900. During the warm medieval period, atypical subtropical plants such as olive trees grew in the Po valley of Northern Italy, and fig trees near Cologne, Germany. Vineyards thrived as far north as Yorkshire in northern England.

The end of the medieval warm period was followed by a cooler period known as the Little Ice Age when global mean temperature fell as far as 0.8°C below the present day. Since about 1800 global temperatures have risen again, dramatically so since about 1980.

This pattern of warming, cooling and warming since AD 1000 is clearly reflected in the retreat, advance and retreat of the snout of the Athabasca Glacier. In AD 1300 the glacier had shrunk to less than half its present size and was only 3 km long. By 1850 the glacier snout had advanced by nearly 5 km and started to flow down the Sunwapta valley, joining up with its northerly neighbour the Dome Glacier. Since 1850 the snout has retreated 1.6 km, leaving the Sunwapta valley and losing its confluence with the Dome Glacier.

Conclusion

The Athabasca Glacier is a typical outlet glacier, flowing out from an icefield. It is one of the most visited glaciers in the world because of its proximity to a major highway and there are concerns over the impact of tourism on the glacier and its environs. It is also one of the most intensively studied glaciers and it reveals an interesting pattern of advance and

retreat in historical times. The behaviour of the Athabasca Glacier shows that it should not be used as evidence of 'unusual' global warming in our present times – the rapid retreat which we observe today has happened before within the past millennia. There is still some way to go before the glacier reaches the reduced state that existed in AD 1300.

Bibliography

Luckman, B.H. et al (1999) 'Earliest Photograph of Athabasca and Dome Glaciers', *Geographie Physique et Quaternaire* vol.53, no. 3, pp 401–405.

Mayewski, P.A., et al (1979) 'Results of the 1978 Athabasca Glacier Expedition', University of New Hampshire, Glaciology Report Series, 56.

The following websites were consulted:

http://airphotos.nrcan.gc.ca/photos101/images/a6619_043.jpg

http://www.crysys.uwaterloo.ca/science/documents/glaciers_infrared.html

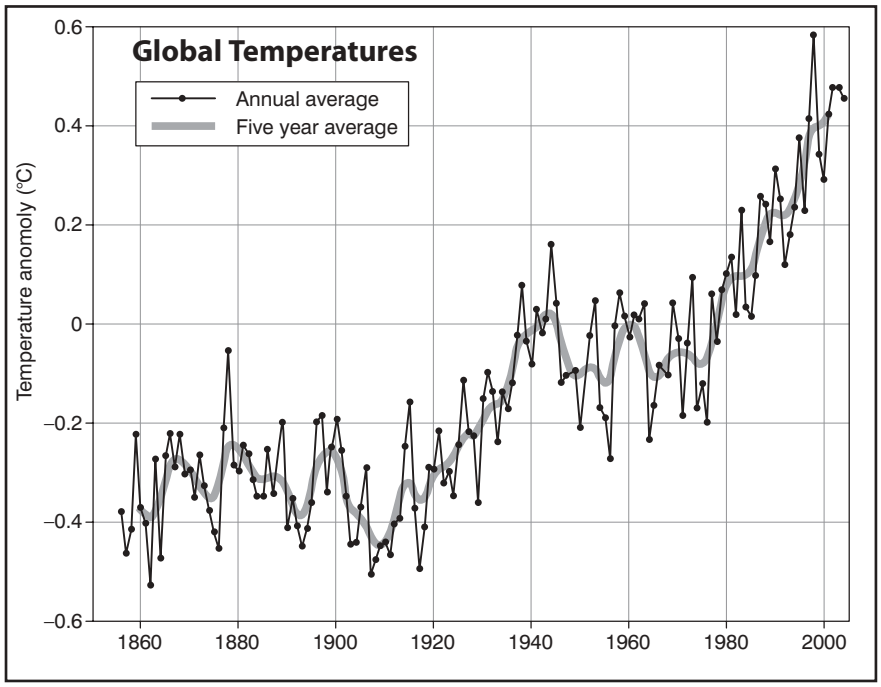
http://www.socc.uwaterloo.ca/glaciers/glaciers_hist_e.cfm

http://www.mta.ca/faculty/socsci/geograph/faculty/laroque/laroque.htm

www.objectivescience.com/articles/hl_recent_warming.htm

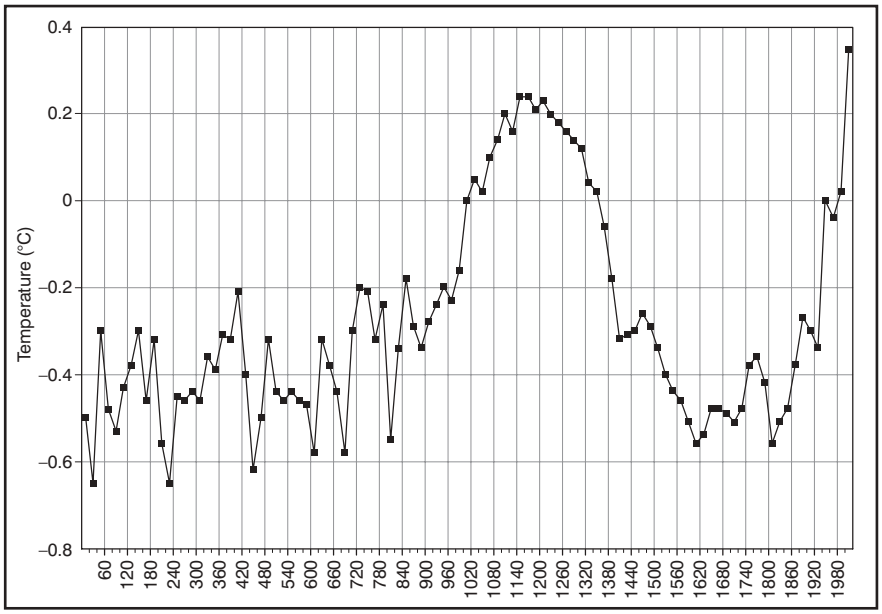
http://www.abheritage.ca/alberta/archaeology/site_profiles_columbia_icefield.html

Figure 8: Global temperature readings from meteorological instruments since 1856 (variation from 1980)



Credit: Phil Jones and Jean Paulutikof, Climatic Research Unit, School of Environmental Sciences, University of East Anglia

Figure 9: Global temperatures AD 0 to the present (variation from 1980)



Focus Questions

1. Figure 10 shows the retreat of the snout of the Athabasca Glacier since 1850.
a) Complete the graph by plotting the statistics in the table below for 1950, 1975 and 2000.

Year	1850	1875	1900	1925	1950	1975	2000
Distance from the Maximum Extent (m)	0	110	260	470	770	1320	1610

b) Describe the trends revealed by the graph.
c) Study Figures 4 and 7. What evidence is there of the glacier's retreat?

2. a) How has the Athabasca Glacier's potential for tourism been exploited?
b) What are the conflicts between promoting tourism and affecting the natural environment in the Athabasca Glacier area?

3. Consider how far the retreat of the Athabasca Glacier since the mid-19th century provides support for global warming as a result of human actions.

Figure 10: The Athabasca Glacier – retreat from the maximum extent of 1850