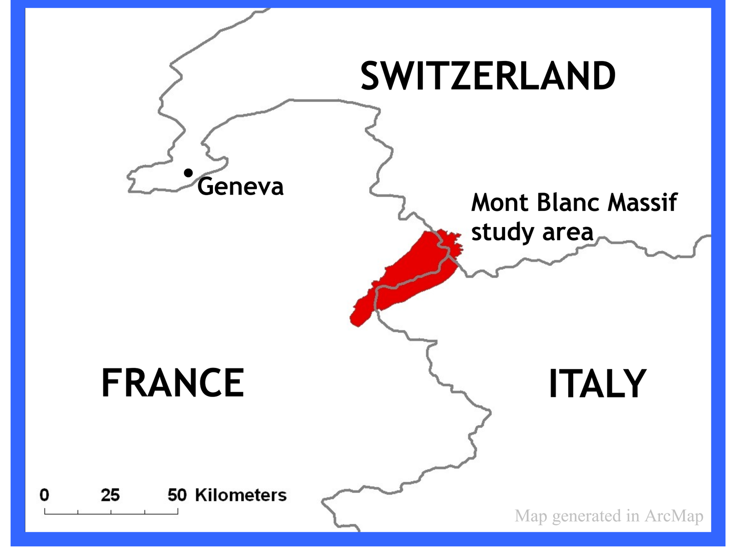
The Snows of Mont Blanc

An analysis of summer snow cover change over 25 years on the Mont Blanc massif

At 4810 m, the Mont Blanc massif and its summit, Mont Blanc, represent the highest mountain range in the Alps and in western Europe. For centuries the mountain and region have been an icon of the Alps and of mountaineering, a sport that was born on its slopes in the 1700s. The range's impressive relief is due to a long geologic history that has allowed for the formation of spectacular cirques, horns, valleys and, most notably, glaciers.

The permanent ice on the range explains how its summit earned its name: Mont Blanc, French for "White Mountain". In the past 25 years, it appears that the massif's glaciers have been experiencing relatively rapid changes, potentially due to anthropogenically-caused climate change. This project intends to examine the change in permanent snow and ice cover on the mountain using techniques employed in the field of Remote Sensing.



Introduction

Climate Change

It has been established that the earth's climate experiences complex fluctuations over time, dependent on factors ranging from the composition of the atmosphere to the subtle irregularities in the planet's rotation and orbit. Furthermore, it has been shown that human activity, namely, humanity's pollution of the atmosphere in the form of greenhouse gases (GHGs) such as carbon dioxide and methane, has potentially initiated patterns of significant changes in climate. In order to fully understand the changes occurring, quantifiable scientific study of these patterns is required. Hopefully, with the conclusions drawn from an ever-expanding body of scientific work related to the subject, the human race can choose to manage the planet on which we reside in a manner that will allow for future generations to enjoy its beauty.

Glaciers

Glaciers provide climatologists a very unique tool to assess changes in climate in a relatively short-term manner. This can be attributed to their extreme sensitivity to even minute changes in mean annual temperature. A glacier is any perennial mass of ice that moves over land. These masses of ice are responsible for much of the land formations on the earth, especially in the northern hemisphere, due to their immense erosive force. For these reasons, a longitudinal glance at the glaciers of the Mont Blanc massif could shed light on the effects of global climate change on the region.

Methodology

In order to quantifiably assess snow cover change on the Mont Blanc massif, a change detection analysis using ENVI software was required. However, before the images used were ready for this analysis, other important manipulations were required.

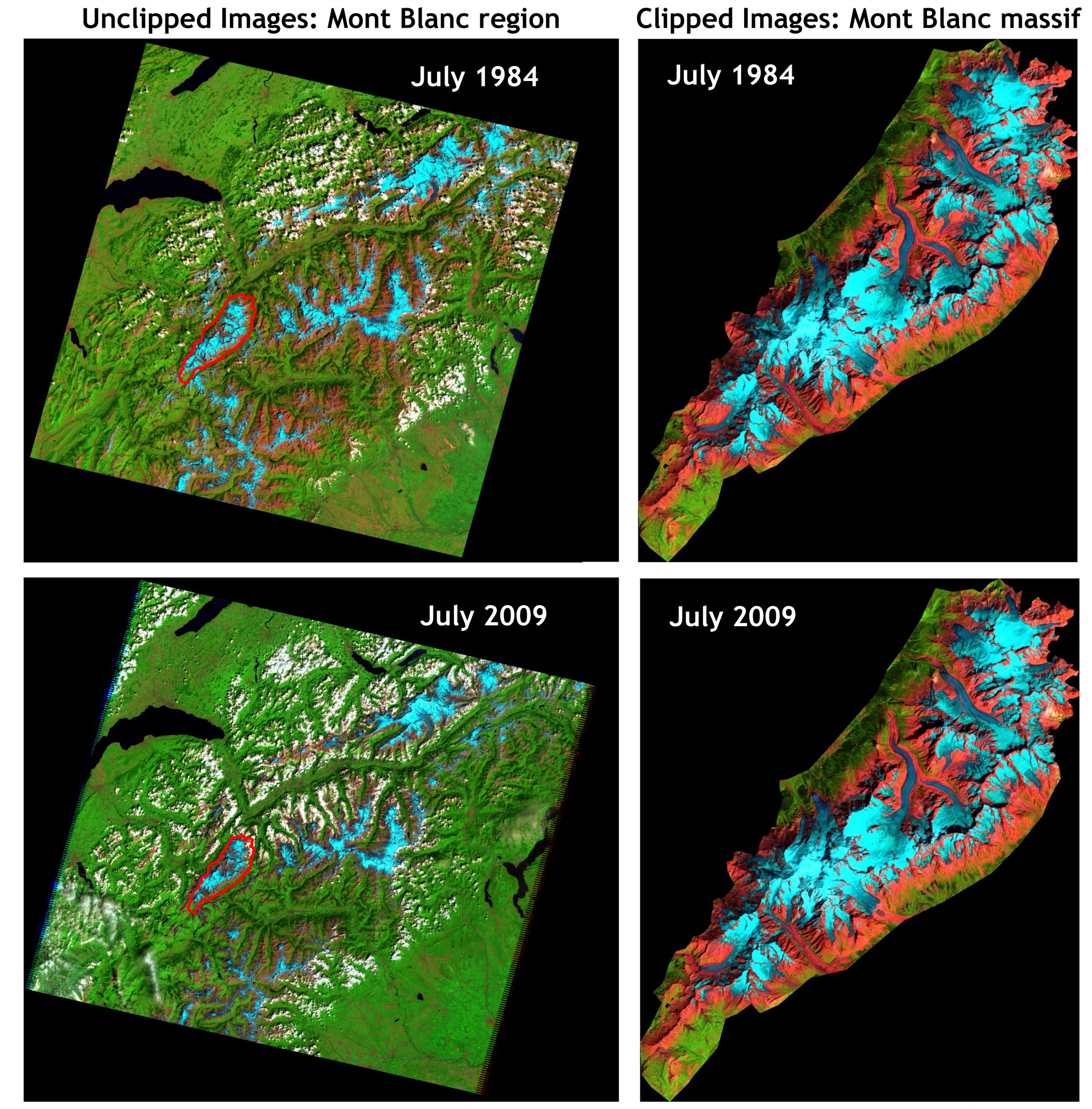
Images

Two Landsat TM 4-5 images of the Mont Blanc massif were used in this analysis - one from July 1984 and one from July 2009. The month of July was chosen as the ideal month for comparison because it represents the most accurate representation of *permanent* snow cover on the massif - most summer melting has occurred by July. Bands 2, 4, 5 and 7 were used, and the spatial resolution of the images was 30 m.

Clipping

The images were first clipped to just include the Mont Blanc massif. This entailed creating a border that passed through the valleys and passes surrounding the massif, then clipping the image to size.

Unclipped Images: Mont Blanc region — Clipped Images: Mont Blanc massif



Above: Unclipped (left) and clipped (right) Landsat TM images from July 1984 (above) and July 2009 (below). The images on the right represents the products of clipping performed by creating a .shp in ArcMap and overlaying it in ENVI (represented by the red polygon overlaying the unclipped images), then exporting as a region of interest. These clipped images allowed for a much more efficient and accurate comparison in the proceeding steps.

Image Registration

Though the clipped images were spatially nearly identical, it was evident that, when linked, the two did not match exactly. To rectify this an image registration was performed in which 10 ground control points were matched between the images. This information was then processed and images representing identical areas were produced, allowing for a more accurate comparison.

Normalized Difference Snow Index

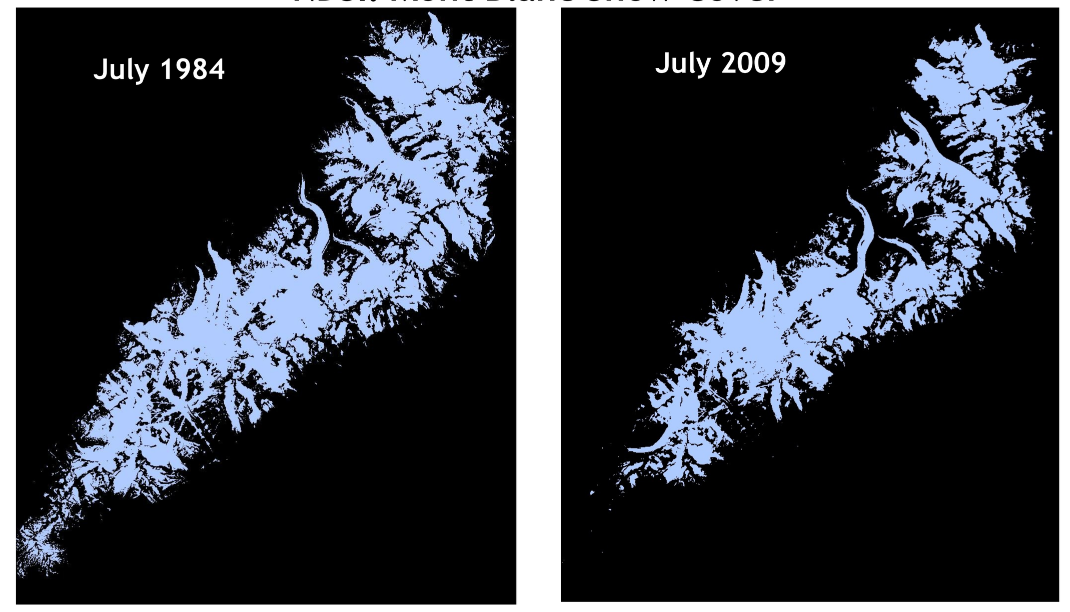
The Normalized Difference Snow Index (NDSI) is an index that identifies snow characteristics by utilizing the inverse relationship between measured values in the green band (high reflectance) and mid-infrared (MIR) band (high absorption).

$$\mathrm{NDSI} = \frac{\mathrm{Green - MIR}}{\mathrm{Green + MIR}}$$

Left: Band math formula for Normalized Difference Snow Index. This formula identifies snow pixels by exposing differences in band reflectance relationships (green and mid-infrared, MIR): pixels with values nearing -1 are unlikely to be snow, those with values nearing 1 are more likely to have snow or ice character-

The calculation of this index resulted in the generation of the following images, representing snow and/or ice cover on the Mont Blanc massif.

NDSI: Mont Blanc Snow Cover



Above: Mont Blanc massif snow cover in 1984 (left) and 2009 (right), as calculated by a Normalized Difference Snow Index (NDSI). The NDSI utilizes the inverse relationship of the green band and the mid-infrared band to identify and map snow/ice cover. NDSI = (green - MIR) / (green + MIR). Blue represents snow/ice, black represents other land cover types.

Change Detection Analysis

After pre-processing (clipping, registration and classification), the final analysis was performed. Snow/ice cover change was analyzed using a change detection technique, which measured what percent of the land surface changed from one classification to the other from 1984 (input state) to 2009 (final state).

Change detection results: Mont Blanc summer snow/ice cover (km^2) from 1984 to 2009

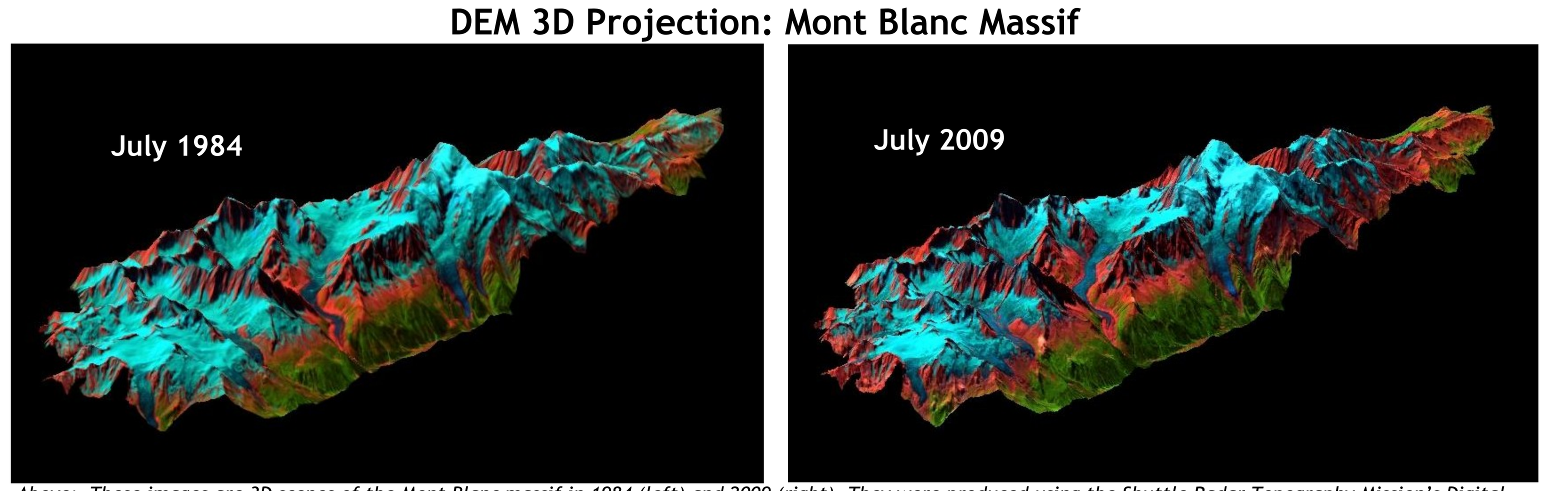
Final State (2009 image)	Input State (1984 image): Not Ice (km^2)	Ice (km^2)	Row Total	Class Total
Not Ice (km^2)	196.08	75.60	271.67	271.71
Ice (km^2)	17.07	143.14	160.21	160.21
Class Total	213.19	218.74		
Class Changes	17.12	75.60		
Image Difference	**58.52 km^2**	**-58.53 km^2**		

Left: This table depicts the results generated by the change detection analysis of the Landsat TM classified images of the Mont Blanc massif from July 1984 (input state) to July 2009 (final state). Overall it was calculated that approximiately 58 km^2 of the massif changed, meaning that 29 km^2 of summer snow and ice cover disappeared.

Conclusions

Overall it was calculated that approximately 58 km^2 of the massif's 1984 ice cover was not ice in 2009, representing a 27% reduction in snow/ice cover on the massif from 1984 to 2009. These results have limitations, to be sure - normal, annual fluctuations in weather, especially winter harshness, could be one of many contributing factors. However, there is a measured difference in snow cover on the Mont Blanc massif from 1984 to 2009. For this, more in depth investigation is necessary to understand the causes and potential ramifications of this trend. The 3D scenes below were produced using ArcScene and the Shuttle Radar Topography Mission's Digital Elevation Model data to emphasize the marked difference in snow cover at lower altitudes on the massif's sides.

DEM 3D Projection: Mont Blanc Massif



Above: These images are 3D scenes of the Mont Blanc massif in 1984 (left) and 2009 (right). They were produced using the Shuttle Radar Topography Mission's Digital Elevation Model (DEM) data and ArcScene, where the false-color image of the Mont Blanc massif was draped over the 3D landscape created with the DEM data. Recession and change in glacial characteristics (indicated by the electric blue color) such as equilibrium line can be seen upon comparison.

The evidence indicating the onset of climate change is extensive. It is of paramount importance that humanity recognizes this fact and responds with care and responsibility to preserve the beauty and precious resources of planet Earth.

Acknowledgements and Works Cited

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Data Sources:

Landsat TM 4-5 data, 1984 & 2009 http://glovis.usgs.gov
SRTM DEM data, Mont Blanc region, http://srtm.csi.cgiar.org

Programs Used:

ENVI 4.6.1, ArcMap, ArcScene

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