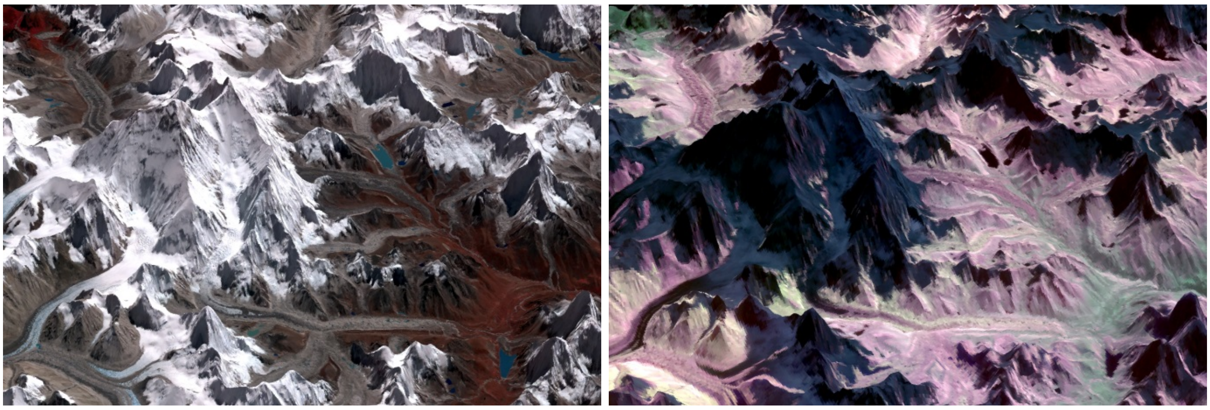
Worldwide retreat of glaciers confirmed in unprecedented detail

The new study *Global Land Ice Measurements from Space* presents an overview and detailed assessment of changes in the world's glaciers by using satellite imagery.

Taking their name from the old Scottish term glim, meaning a passing look or glance, in 1994 a team of scientists began developing a world-wide initiative to study glaciers using satellite data. Now 20 years later, the international GLIMS (Global Land Ice Measurements from Space) initiative observes the world's glaciers primarily using data from optical satellite instruments such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and Landsat .

With more than 150 scientists from all over the world contributing to this compilation, this book from GLIMS is the most comprehensive report to date on global glacier changes. While the shrinking of glaciers on all continents is already known from ground observations of individual glaciers, by using repeated satellite observations GLIMS has firmly established that glaciers are shrinking globally. Although some glaciers are maintaining their size, most glaciers are dwindling. The foremost cause of the worldwide reductions in glaciers is global warming, the team writes.

The study has 25 regional chapters that illustrate glacier changes from the Arctic to the Antarctic. Other chapters provide a thorough theoretical background on glacier monitoring and mapping, remote sensing techniques, uncertainties, and interpretation of the observations in a climatic context. The book highlights many other glacier research applications of satellite data, including measurement of glacier thinning from repeated satellite-based digital elevation models and calculation of surface flow velocities from repeated satellite images.



Left: *View on Mt. Everest and the infamous Khumbu ice fall (middle left) in a green-red-near infrared ASTER satellite image. Snow and ice appear bright in this part of the optical spectrum.* ***Right:*** *The same scene in a short-wave infrared image. Snow and ice appear very dark, thus helping researchers to map the glaciers by exploiting the difference between both image types .*

These tools are key to understanding local and regional variations in glacier behavior, the team writes. The high sensitivity of glaciers to climate change has substantially decreased their volume and changed the landscape over the past decades, affecting both regional water availability and the hazard potential of glaciers. The growing GLIMS database about glaciers also contributed to the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report issued in 2013. The IPCC report concluded that most of the world's glaciers have been losing ice at an increasing rate in recent decades.

Methods used in the study:

In a huge international effort researchers have compiled an unprecedented report on the global status of glaciers (*Global Land Ice Measurements from Space, GLIMS*). To achieve this, they have not relied on a single technique, but rather combined a range of modern satellite methods. Satellite images from the visible and infrared spectrum were the workhorse of the worldwide glacier mapping for this report. The method exploits the unique optical properties on snow and ice, where these surfaces appear bright in the visible section of the optical spectrum but very dark in the shortwave infrared spectrum. Satellite sensors that are able to sense both sections of the optical spectrum, such as *Landsat* or *ASTER*, are thus used to map snow and ice in a robust and straightforward way on a global scale.

Problems start where glaciers are covered by debris from the rock walls surrounding them – a typical phenomenon, for instance, in the Himalayas and Alaska. There, the optical properties of rock debris prevail over those of the underlying ice, which makes the glaciers not easily discernible. In these cases researchers used thermal satellite data, which are able to detect tiny temperature differences between the glacier surface and the moraines around, satellite radar data, and topographic information. Using radar interferometry, even smallest movements of a centimetre on the glacier can be detected and thus help to discriminate a slowly flowing glacier from its stable surroundings. Researchers use similar methods to map the growth of glacier lakes, an important task as glaciers increasingly are melting and producing often-hazardous, unstable lakes.

Whereas variations in glacier area and length are among the best representations of climatic changes, knowledge of the water resources stored in glaciers and their seasonal and long-term release to rivers and ground water requires monitoring of glacier volume changes over time. Researchers use satellite stereo techniques where the three-dimensional surface of a glacier is reconstructed based on two (or more) satellite images taken from different positions – very similar to how human beings are able to sense form and distances of objects with their two eyes. In addition to stereo methods, researchers measure glacier elevations and their variations over time using a satellite laser (*ICESat*) that sent light pulses from space to Earth, recorded the light reflection and measured the travel time of the pulse to determine the distance from the spacecraft to the glacier by almost centimetre accuracy.

The third glacier parameter measured, and an equally important one compared to glacier area and volume changes, is the ice flow in glaciers that transports the snow surplus from the upper glacier zones to the lower ones where ice melt prevails. Researchers track features such as dust or debris patterns on the ice over several repeat optical or radar satellite images and follow thus their movement over time. Scientists are using satellite imaging, thermal measurements, and satellite microwave techniques to track other important changes, such as melting of snowfields and ice on glaciers.

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