Glaciers Going Going Gone

...it is that a man who keeps company with glaciers comes to feel tolerably insignificant by and by. The Alps and the glaciers together are able to take every bit of conceit out of a man and reduce his selfimportance to zero if he will only remain within the influence of their sublime presence long enough to give it a fair and reasonable chance to do its work. – Mark Twain, A Tramp Abroad

There is a glacier in Iceland, Solheimar, which has retreated a great deal, and every time I go back there and see what's not there any more, it does something to the heart. It makes you realize it's possible for a gigantic natural element to just disappear. – James Balog

In 1991, while traversing an Alpine glacier on the Austrian-Italian frontier, hikers discovered the remains of a man in the melting ice.¹ At first it was believed this human body might be the victim of a recent mountaineering accident. Later Swiss researchers determined that in fact this was a man that was naturally mummified as the result of being covered by snow shortly after his death roughly 5,300 years ago.

This 5300-year-old man, nicknamed "The Iceman" and later named Ötzi, was perhaps the most celebrated and scientifically exciting mummy that has recently been found. Other bodies are also emerging for the very first time since they were lost long-ago to an icy grave, as well as other artifacts, such as a centuries-old moss, Roman coins, an Iron Age horse, ancient forests² and even a well-preserved leather shoe last worn 3,400 years ago during the Bronze Age.³ Bodies and items left on the surface had long ago been covered with snow which was eventually compacted to ice. This protected them from decay and disturbance for hundreds or thousands of years making the ice a type of time machine giving archeologists an exciting opportunity to learn about the past.

The reason for all of these recent discoveries is that all around the world glaciers are melting and retreating. While providing a treasure trove of archaeological discovery, the melting glaciers are a disturbingly visually vivid indication of a warming planet. While these discoveries are exciting, the boon is likely short-lived as the ice thaws and vanishes from places where it has been for thousands of years.

Glaciers that exist today are remnants of the last ice age. Thick sheets of ice advanced and retreated across most continents several times before withdrawing to the polar regions about 10,000 years ago; continental ice sheets still cover Greenland and Antarctica.⁴

Glaciers are slow moving rivers of ice that are pushed along by accumulating snow and ice at higher altitudes. They flow downhill at a speed of a hundred to thousands of meters per year.⁵ Glaciers grow through snowfall and shrink through melting and when water evaporates directly from solid ice, which is a process called sublimation. Glaciers that end in a lake or the ocean also shrink when ice chunks from the edge of a glacier break off into the body of water, which is known as iceberg calving.

While almost three quarters of the Earth's surface is covered with water, over 96.5% is in the salty oceans and seas with only the remaining 3.5% fresh water. Over 68% of that fresh water on Earth is found in the frozen Arctic and Antarctic icecaps as well as mountain glaciers with just over 30% found in ground water.⁶ That leaves only about 0.3% of fresh water found in the surface water of lakes, rivers and swamps.⁷ Amazingly, despite abundant quantities of water on Earth, most of it is not directly usable by many living things, including humans, making fresh water a rather scarce resource. The 171,000 glaciers worldwide, excluding the Greenland and Antarctic ice sheets, contains ice of nearly 170,000 cubic kilometers (41,000 cubic miles)⁸ equal in volume to over 65 million Great Pyramids of Giza.⁹ This makes mountain glaciers one of the most important reservoirs that provide a reliable fresh water to natural ecosystems and hundreds of millions of people.

In Asia, the Tibetan Plateau is the largest high-altitude landmass on Earth covering 2.5 million square kilometers [965,000 square miles].¹⁰ The Tibetan Plateau is about the size of Spain, France, Germany, Italy, the Netherlands, Belgium, Switzerland, Austria, Poland, the Czech Republic,

Slovakia, Hungary and Slovenia combined.¹¹

The Tibetan Plateau is referred to by some scientists as the "Third Pole" because its ice mass contain the largest reserve of fresh water outside of the Antarctic at the South Pole and the Arctic at the North Pole. Its immense glacial ice sheets are made up of more than 45,000 glaciers¹² covering an area of over 100,000 square kilometers (38,600 square miles),¹³ roughly the area of the state of Kentucky. The Himalayas, that separate the plains of the Indian subcontinent from the Tibetan Plateau, contain 100 times as much ice as the Alps providing for more than half of the drinking water for 40% of the world's population.¹⁴



This landmass is literally the roof of the world with a mean altitude of 4,000 meters [13,000 feet]. It is dotted with the world's highest mountains, glaciers, rivers, grassland, forests, and lakes to form one of the outstanding zones for biological diversity on earth.¹⁵

Considered "water towers of the world," the melt water from glaciers of the Third Pole feeds nine of the biggest rivers in Asia, including the Ganges, Yangtze, Yellow, Brahmanputra and Mekong. These rivers supply water that is a lifeline to twelve of the most densely populated nations of Asia,¹⁶ including China and India. Societies along these rivers have grown, expanded and been nurtured by the supply of abundant water that supports daily life, agriculture, livestock and industry. Millions of people of Asia are dependent on water flowing off the Tibet Plateau for their very existence.

Temperatures on the plateau are rising twice as fast as other parts of the world. Over western China the atmosphere has warmed 0.7°C [1.26°F] over the past 50 years.¹⁷ Temperatures measured in 2006 on the Tibetan Plateau were the warmest since records for the region began to be kept in

1951, while analysis of ice cores from glaciers indicate that the 1990s were the warmest decade of the previous 1,000 years.¹⁸

Heat in the Himalayas has increased by 1°C [1.8°F] since the 1950 causing thousands of glaciers to retreat by an average of 30 meters [98 feet] each year.¹⁹ From 1930 to 1998 the Western Sichuan's Hailuogou Glacier has retreated 1,700 meters [1 mile]. Glaciers in the eastern part of the Kunlun Mountains, which forms the northern edge of the Tibetan Plateau, have retreated by 17% over the past 30 years.²⁰

Photographs taken in the 1930s, 1970s, 1980s and 2007 show that both ice volume and glacial surface conditions of the Ata Glacier have dramatically changed.²¹ The glacier has lost almost 8% of

its original area and has retreated by nearly 10% as measured in from the early 1960s to 1999.²² In the 1990s the glaciers shortened 1.9 times faster than in the approximately 30 years before 1990.

The Rongbuk Glacier on the north face of Mount Everest has retreated 170 to 270 meters [558 to 886 feet] from 1966 to 1997. Since Sir Edmund Hillary and Tenzing Norgay were the first to reach the summit of Everest much of that glacier has turned to meltwater and retreated about 5 kilometers [3 miles] up the mountain.

> "Back in 1953 when Hillary and Tenzing set off to climb Everest they stepped out of their base camp and straight on to the ice. You would now have to walk for over two hours [from the same site] to get on to the ice."²³

The new snows that fall each year cannot make up for the ice loss and as a result glaciers retreat upslope and shorten. Some smaller glaciers are shrinking so fast they are predicted to entirely disappear with then next few decades. Since the 1980's the total amount of glacial ice



Dramatic retreat of Ata Glacier, southeast Tibetan Plateau, from 1933 (upper) to 2006 (lower) due to global climate changes.

in the Tibet and Himalaya region has decreased by about 6%.²⁴ According to Jeff Kargel of the U.S. Geological Survey:

"Glaciers in the Himalayas are wasting at alarming and accelerating rates, as indicated by comparisons of satellite and historic data, and as shown by widespread, rapid growth of lakes on the glacier surfaces."²⁵

Many Himalayan glacial lakes are forming and are quickly filling up because of this accelerated melting. The melting glaciers cause floods and landslides by increasing the volume of river runoff and lakes that grow and collapse. Glacial-lake outburst floods and glacial debris-flow hazards have become more serious since the 1980s.²⁶

...glacier ice mass loss since the 1980s has increased the magnitude and frequency of flash floods in the Gezhe river because ablation [the loss of snow and ice by melting or evaporation] of the glacier surface accelerated as a consequence of atmospheric warming.²⁷

Glacial lakes have broken their banks in Nepal more than 20 times since the early 1960s. Tsho Rolpa Lake in Nepal has grown sixfold since the 1950s. A flood from this lake could cause serious damage as far as 100 kilometers [62 miles] downstream in the village of Tribeni threatening 10,000 lives.²⁸ The Imja Tsho glacial lake in Nepal was drained in 2016 to safe levels²⁹ because if it had burst its banks it would send a 100 meter [328 foot] wall of water down the valley.

Data from the Himalayan mountains show that annual temperature in the region has increased, indicating that glacier shrinkage and large ice mass deficits can largely be attributed to the rapid air temperature rising.³⁰ Also, a number of other human actions help accelerate the melting of the glaciers and exacerbate the resulting problems. "Black carbon" is the soot-like byproduct of the use of coal, burning of agricultural waste or forest fires. It reinforces the adverse effects of climate change as it deposits on the glaciers causing them to absorb more solar heat and accelerating melting.³¹ According to James Hansen, who is an American adjunct professor directing the Program on Climate Science, Awareness and Solutions of the Earth Institute at Columbia University:

"Tibet's glaciers are retreating at an alarming rate. Black soot is probably responsible for as much as half of the glacial melt, and greenhouse gases are responsible for the rest."³²

Tibet has lost nearly 50% of its forests decreasing from 25.2 million hectares in 1959 down to 13.57 by 1985.³³ This large scale deforestation has caused Bangladesh and China to face unprecedented floods.³⁴ Deforestation adds significantly to global warming because once trees are felled the sequestered carbon is released and the trees are no longer absorbing carbon dioxide from the atmosphere.

One of the driving factors for the Chinese invasion in 1949 [of Tibet] was the quest for rare and precious minerals to fuel industrial growth. According to Chinese statistics, there are over 126 different minerals in Tibet including copper, gold, uranium, borax and iron which Tibet has in abundance and which are rapidly being depleted in China itself. Tibet's landscape has been transformed with roads, railways, mines, housing and hydropower plants to support the harvesting of these materials and, as a result, rich agricultural land has been lost, water sources polluted and soil contaminated. According to Chinese estimates, at least 30 percent of Tibet's arable land is now considered degraded.³⁵

If this melting continues at the current rate, two-thirds of the existing Himalayan glaciers will be gone by 2050,³⁶ with a projected a 43% average decrease in glacial area by 2070 and a 75% decrease by 2100.³⁷ Glaciers in the Garhwal Himalaya in India are retreating so rapidly that researchers believe that most central and eastern Himalayan glaciers could virtually disappear by 2035.³⁸

To the north of the Tibetan Plateau across the Tarim Basin and Taklimakan Desert lies the Tian Shan, also called the Celestial Mountains. The Tian Shan extend 2,500 km (1,550 miles) east-to-west

across Central Asia. The glaciers in the Tian Shan are melting and have lost 27% of their mass since 1961 losing on average 5.4 gigatons of ice per year.³⁹ A male African elephant might weigh at most 6.8 metric tons,⁴⁰ meaning that the Tian Shan is losing the equivalent of nearly 800 million African elephants worth of ice annually.

GFZ German Research Centre for Geosciences at Rennes University noted that "currently, the Tien Shan is losing ice at a pace that is roughly twice the annual water consumption of entire Germany." Snow and glacier melt from the Tien Shan is essential for the water supply of Kazakhstan, Kyrgyzstan, Uzbekistan and parts of China. Because meltwater from the glaciers supplies the Fergana Valley, one of the largest irrigated areas on earth, the impact on farmers could be enormous. The melt there is four times the global average and because of rising summer temperatures the remaining ice could fall by another 50% by 2050.⁴¹

According to a 2006 United Nations report, Asia already has less fresh water per person than any other continent outside of Antarctica.⁴² In Africa, household water use averages 47 liters per person per day; in Asia the average is 95 liters per person per day; in the United Kingdom the average is 334 liters per person per day and in the United States the average is 578 liters per person per day.⁴³ As many Asian families advance economically, they aspire to live the American lifestyle further straining water resources. As temperatures increase and the ice melts, this essential supply of water is threatened with massive impacts on both the ecology and human livelihoods. The nearly 2

billion people in China, India, Pakistan, Bangladesh and Bhutan will almost certainly be at serious risk of acute water shortages as demand rapidly increases and the glacial water that supplies vital rivers disappears.

Across the world there are somewhere between 150,000 and 200,000 mountain glaciers and nearly all of them are shrinking. From Mount Kilimanjaro to Glacier National Park in Montana are the well-publicized examples of the glacial vanishing act. The fresh snow that falls annually isn't enough to compensate for the melt causing the world's glaciers to retreat and grow smaller at on average about 10 meters (33 feet) each year.⁴⁴

The famed snows of Kilimanjaro have melted more than 80% since 1912. When President Taft signed the bill establishing Glacier National Park in 1910 there were an estimated 150 glaciers. Today that number has decreased to fewer than 30 with most of those having shrunk in area by two-thirds, with Daniel Farge of the U.S. Geological Survey Global Change Research Program



Shepard Glacier, Glacier National Park, MT, 1913 (top) and 2005 (bottom).

predicting most, if not all, the park's glaciers will disappear by mid-century.⁴⁵

"Things that normally happen in geologic time are happening during the span of a human lifetime," says Fagre. "It's like watching the Statue of Liberty melt."

According to scientists it is inevitable that the contiguous United States will lose all of its glaciers within a matter of a few decades.⁴⁶ The greater than 1,000-year-old Arikaree glacier, located in Roosevelt National Forest in Colorado is thinning by about 1 meter (3.2 feet) annually over the past decade and is expected to vanish within 25 years. Dr. Farge stated that glaciers started to shrink from around 1910 and then entered "rapid and continual" melting from the 1970s onwards.

"This is the first time in 7,000 years they've experienced this temperature and precipitation. There's no hope for them to survive. We'd need a major reversal where it would get cooler, not just stop getting warmer. There's nothing to suggest that will happen."

In Canada, the Peyto Glacier in the Canadian Rockies in Banff National Park is losing as much as 3.5 million cubic meters of water each year.⁴⁷ The diminishing snowpack also threatens the health of Western watersheds and increase the risk of forest fires. Approximately 70% of that glacier is already gone and its retreat will have a serious impact on the Mistaya and North Saskatchewan rivers that are fed by this glacier.

British Columbia's 17,000 glaciers — both in the Rockies and along the Pacific coast — are losing 22 billion cubic meters of water annually. That's equivalent to refilling a 60,000-seat football stadium 8,300 times.

Mountaintop glaciers in Colombia have lost 18% of their area in just seven years with six glaciers shrinking from 45 square kilometers (17.4 square miles) in 2010 to 37 (14.3) by 2017.⁴⁸ To the south in Peru over the past 40 years the glaciers have shrunk by 40% leaving behind nearly 1,000 high altitude lakes in the basins left behind by the retreating glaciers. The glacial retreat and newly formed lakes left behind can cause serious destruction to towns and infrastructure.⁴⁹ In 1970, an earthquake triggered a glacial avalanche of ice, rock and mud that buried the town of Yungay, Peru quickly killing 20,000 people.⁵⁰ In 2010 a huge portion of a glacier broke off and plunged into a lake in Peru causing a 23 meter [75 foot] tsunami wave killing three people and destroying a local water processing plant.⁵¹

It was one of the most concrete signs yet that glaciers are disappearing in Peru, home to 70 percent of the world's tropical icefields. Scientists say warmer temperatures will cause them to melt away altogether within 20 years.

Peru's 2,679 glaciers are the source of the vast majority of the country's drinking and agricultural water.⁵² The government has used this source of water to irrigate the desert turning it into more than 100,000 acres of farm land that produces items such as asparagus and blueberries that are shipped to far off places like Denmark and Delaware.⁵³ Those glaciers continue to retreat and vanish with scientist estimating that much of it will be gone by 2050. Once that fresh water supply is gone the transformed bountiful dessert will revert back to an empty dessert land.

"We're talking about the disappearance of frozen water towers that have supported vast populations," said Jeffrey Bury, a professor at the University of California at Santa Cruz who

has spent years studying the effects of glacier melt on Peruvian agriculture. "That is the big picture question related to climate change right now."

Not only is the water supply threatened, as Peruvian glaciers retreat metal-rich rocks are being exposed for the first time in thousands, or even millions, of years. The meltwater carries these metals, such as lead, arsenic, cadmium, manganese and iron, downstream contaminating water and soil.⁵⁴ The metals are leaking into the groundwater, turning entire streams red, killing livestock and crops, and making the water undrinkable.⁵⁵

The analysis of 45,000 observations taken since 1894 of 2,000 glaciers showed that from 2001 to 2010 glaciers lost on average 75 centimeters [29.5 inches] of their thickness each year. This rate was twice the rate in the 1990s and three times that in the 1980s showing a rapid acceleration of glacial ice losses.⁵⁶ Lead author Michael Zemp of the World Glacier Monitoring Service at the University of Zurich, Switzerland highlighted the seriousness of the study:

"The first decade of the 21st century, from 2000 to 2010, saw the greatest decadal loss of glacier ice ever measured. It's without precedent... globally, we're now losing treble the total ice volume of the European Alps each year. We were shocked."

According to NASA the world has lost approximately 400 billion tons of ice from mountain glaciers since 1994,⁵⁷ or over the weight of 1,000,000 Empire State Buildings.⁵⁸ In the 2017 State of the Climate report published by the American Meteorological Society the cumulative mass balance loss from 1980 to 2016 was 19.9 meters [65 feet]. This is the equivalent of cutting a 22-meter-thick (72-foot-thick) slice off the top of the average glacier.⁵⁹ Climate scientists estimate that if the world continues warming at the same rate, 90% of its glaciers will be gone by 2100.⁶⁰ Archeologist Lars Pilö notes with a sense of inevitability, "they've been here for 6,000 years, so it's incredible to think they'll be gone in 100."

As temperatures rise ocean water warms and expands in volume as well as more water flowing to the seas from melting glaciers and ice caps. This combination of effects has played the major role in raising average global sea level. Although glaciers store less than 1% of global ice mass, they are responsible for the majority of sea level rise.⁶¹

Since 1900 the global sea level has risen by approximately 20 centimeters (7.9 inches). A 2012 study found that between 1902 and 2009, melting glaciers contributed 11 centimeters (4.3 inches) to that sea level rise.⁶² The rest was from warming and thereby expanding sea water, melting Greenland and Antarctic ice sheets and changing terrestrial water storage in dammed lakes and groundwater reservoirs. Future glacier melting is project to raise sea level an additional between 15 to 22 centimeters (5.9 to 8.7 inches) by the 2100. If all the glaciers were to melt, global sea levels would rise about 43 centimeters (17 inches).⁶³ Compared with the potential sea level rise from the Greenland and Antarctic ice sheets, the volume of land-based glaciers is comparatively small. However according to Matthias Huss, a glaciologist at the University of Fribourg in Switzerland:

...mountain glaciers are still a concern because they "react very fast to higher temperatures and a considerable retreat is very likely in the next decades."⁶⁴

Glaciers are somewhat slow to react to climate change and aren't directly reacting to recent warming. Instead current ice loss is a result of the warming of the planet's climate system over the course of the last century. Greenhouse gas emissions have already triggered a melting momentum which is already in the system with little that can be done to alter that trajectory.

Today, many glaciologists are more concerned with predicting when various glaciers will disappear. In many parts of the world—including the western United States, South America, China, and India.⁶⁵

Daniel Farinotti, researcher at the Swiss Federal Institute for Forest, Snow and Landscape Research in Birmensdorf, Switzerland noted that even if we halted emissions of carbon dioxide tomorrow, the glaciers would continue to melt for several decades because of the carbon dioxide already in the atmosphere.⁶⁶ According to Ben Marzeion, of the Institute of Geography at the University of Bremen:

"Around 36 percent of the ice still stored in glaciers today would melt even without further emissions of greenhouse gases. That means: more than a third of the glacier ice that still exists today in mountain glaciers can no longer be saved even with the most ambitious measures."⁶⁷

There is a certain amount of melting that has already occurred and will continue to occur no matter what action is taken. As glaciers continue to disintegrate, the icy white surfaces that once reflected sunlight back up into space is replaced with exposed darker surfaces that absorb that heat and raise temperatures. This positive feedback loop accelerates warming as these darker surfaces are exposed.

While there is evidence that some of the glacial melt is independent of human induced factors scientist have found "unambiguous evidence of anthropogenic glacier mass loss in recent decades."⁶⁸ Yet, altering human actions that impact glaciers can reduce the amount of damage to make it less catastrophic. Georg Kaser, a climate scientist at the University of Innsbruck in Austria noted that "our current behavior has an impact on the long-term evolution of the glaciers -- we should be aware of this." Scientist calculated that for every kilogram of CO_2 that is emitted causes 15 kilograms of glacier melt over the long term. This means the one kilogram (2.2 pounds) of glacier ice is lost for every five hundred meters (1/3 of a mile) driven by a conventional car.⁶⁹

Time and water are running out for the world and the picture is very bleak. If there are vast shortages of water, which is almost certainly going to happen in the foreseeable future, we are talking about a colossal human disaster. The United Nations estimates that two-thirds of the world's population will live in areas of water stress within the next 20 years, with much of that population living in Asia.⁷⁰

Rapid population and economic growth is putting strain on the two linked resources of energy and water. Energy production produces greenhouse gases that heat up the atmosphere while simultaneously diminishing and contaminating the sources of water that are vital to life. China has extensively adulterated its own major rivers through unbridled industrialization and now threatens the ecological viability of river systems to meet its unquenchable thirst for water and energy.

China's rapid economic growth over the past few decades has come at a heavy cost of severe environmental and resource degradation and massive greenhouse gas emissions. This may bring "catastrophic consequences for future generations" because some of the harm already done is irreversible.⁷¹ Much as damage to the rain forest affects the people of the world the degradation of the Tibetan plateau has consequences for peoples far beyond the plateau.

The state of glaciers is closely linked not only to sea level rise, but to questions of water availability and, thus, food security. Without this mass storage of frozen fresh water our way of life, which is based on climate as we have known it for thousands of years, is going to be radically altered. The mindset of "economic growth at any cost" is ultimately going to be immensely expensive as the ice that has existed for centuries vanishes in just a relatively few years. Glaciers have been retreating for decades and it is no longer an issue of if glaciers are going to melt, but how fast and how humans and life will be able to adapt to these severe and unyielding changes.

Mountain glaciers are a powerfully demonstration how climate change has already and still is reshaping the world and it's a world with a great deal of less fresh water. If society cannot address glacier retreat by mitigating and adapting in the coming decades with the climate warming and the relentless impact on these water resources it raises the serious specter of water wars in Asia and in other parts of the world. Addressing glacier retreat is question of survival for billions that we can address or continue to whistle past our own cemetery.

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