CODEL Boxer, Ilulissat, Greenland, July 27-29, 2007.

The great ice sheet of Greenland, hundreds of miles across, over a thousand miles long, and two miles thick in the middle, would raise global sea level about 23 feet if totally melted. In 2001, the UN IPCC noted great uncertainties but suggested that the ice sheets of Greenland and Antarctica, taken together and averaged over the next century, would grow slightly, with increasing snowfall in Antarctica and on the colder parts of Greenland exceeding increasing melting, and with little change in ice flow. In 2007, the IPCC noted that new evidence indicates warming-induced shrinkage of the ice sheets, in part because of increased ice flow in places such as the Jakobshavn Glacier at Ilulissat. Although the contribution to sea-level rise from the ice sheets is small so far, and complete loss of an ice-sheet does not seem plausible over times less than centuries, the ice-flow acceleration caused the IPCC to state in 2007 that "understanding of these effects is too limited to… provide a best estimate or an upper bound for sea level rise". The 2007 IPCC does not rule out the possibility of complete disintegration of the Greenland ice sheet over sufficiently long times.

Two physical processes are especially important in the ice-flow speed-up, and are evident at and near the great Jakobshavn Glacier, a fast-moving stream of ice draining the vast, slower-flowing ice sheet. The ice reaching the ocean once remained attached for a while, forming a floating ice shelf, and friction between the ice shelf and the rocky walls helped hold back the ice behind. Almost total loss of the ice shelf at Jakobshavn, likely in response to warming, led over the last 20 years to more than doubling the speed of what had been one of the fastest, if not the fastest, ice flows on the planet. In addition, farther inland, increasing melting feeds more water to the bed of the glacier, lubricating faster ice flow.

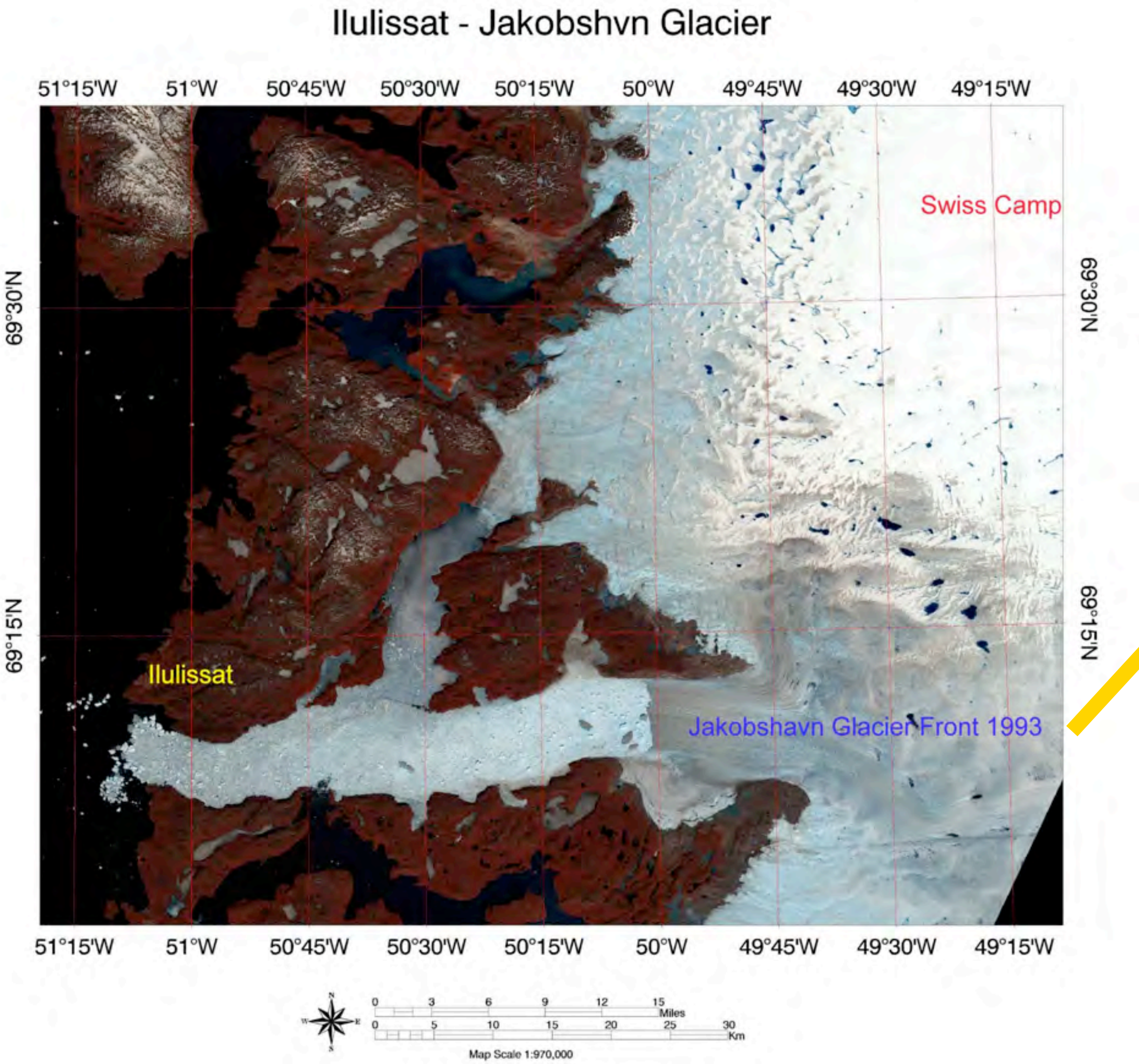
Climate history shows that Greenland has warmed and cooled naturally in the past, and that the ice responded, growing with cooling and shrinking with warming. The ice survived somewhat warmer temperatures in a somewhat reduced state, but largely or completely disappeared in response to too much warming. How much warming is too much remains uncertain, but emerging evidence indicates that continuing business-as-usual fossil-fuel burning could reach a temperature this century sufficient to melt the ice sheet, although that melting would require at least many centuries.

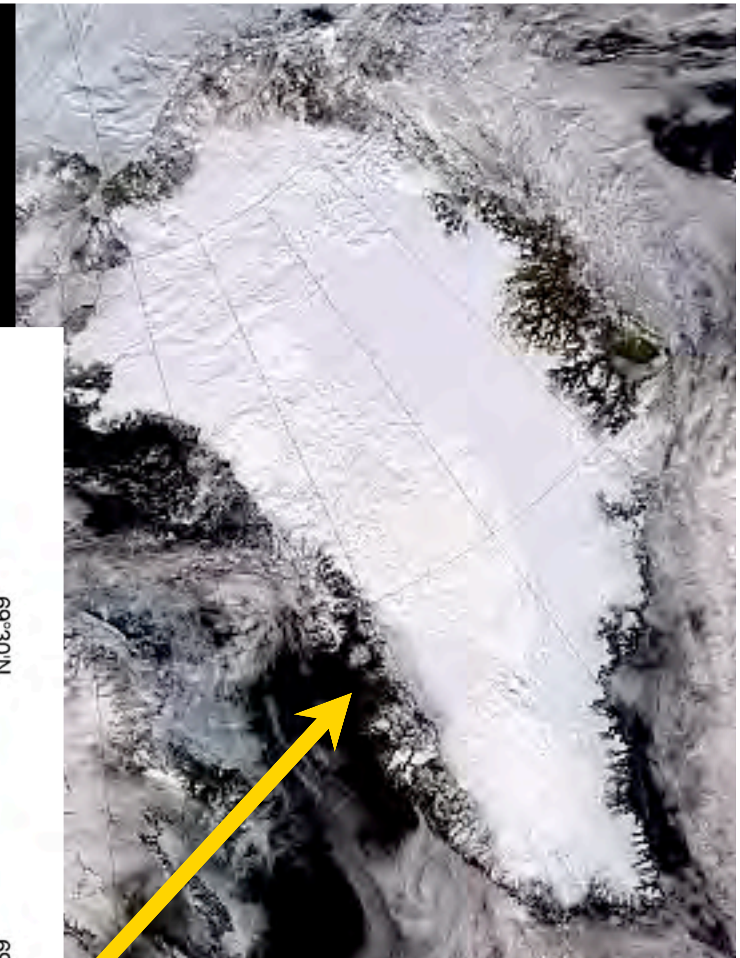
The natural changes in temperature, from multi-millennial variations in Earth's orbit, gradual natural changes in greenhouse-gas concentrations, volcanic eruptions, and other causes, were almost always much slower than the expected warming of the next centuries if we continue on our present path. The most recent warming started a bit over a century ago from natural changes in sun, volcanoes and perhaps other things. But, the warming accelerated as those natural causes stabilized, and as carbon dioxide and other human-produced greenhouse gases rose rapidly; the human fingerprint on the recent warming can be identified scientifically with high confidence. Although the recent warming is scientifically unequivocal, it is not large yet, and not nearly so large as the warming expected if human fossil-fuel burning continues unabated.

CODEL Boxer had a first-hand look at the anomalously rapid motion of ice from Greenland to the sea, and at the recently increased puddling of meltwater in the crevasses, where it can contribute to break-up of the ice and accelerated motion. The tracks of ancient glaciers showed clearly that the ice has fluctuated in the past, and our knowledge of the past climates shows that warming melted the ice while cooling grew the ice. Melting contributes directly to sea-level rise, so this knowledge has obvious implications for the future.

All photos and annotations by Richard B. Alley, and freely available to the good folk of CODEL Boxer.

Greenland (NASA image, right) and close-up false-color image (below, courtesy Konrad Steffen, U of Colorado). CODEL boxer visited Ilulissat, the Isfjord just to the south, and the front of Jakobshavn Glacier, which has retreated notably since this 1993 image.

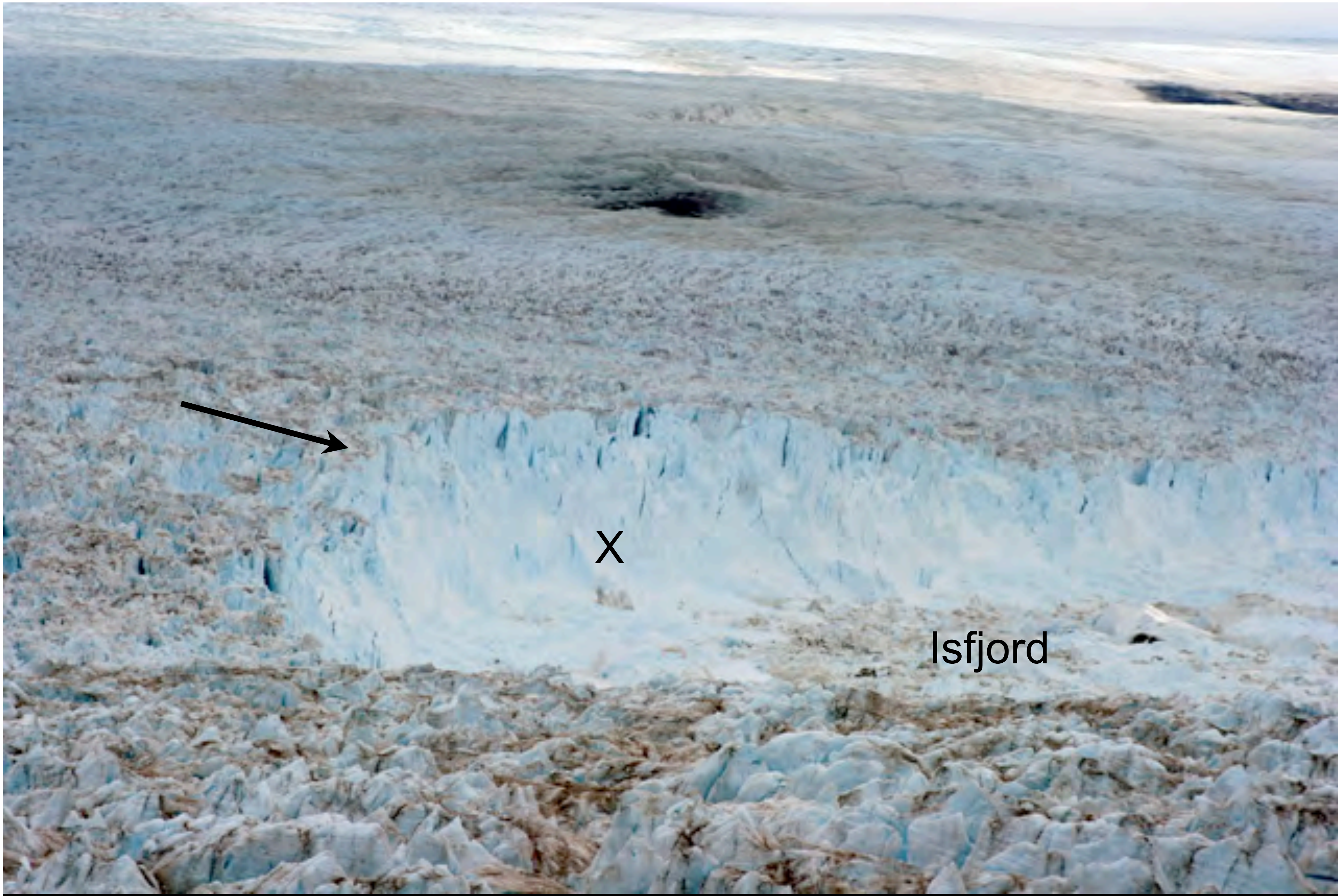




Icebergs. Jakobshavn. These are little ones. The iceberg that sank the Titanic probably came from here, but was much bigger.

GLACIER TRACKS. The yellow arrows at left and right point along a moraine, loose rocks pushed up along the side of the glacier that flowed where the pink arrow is, probably about 12,000 years ago. (Moraines also are formed at the ends of glaciers.) Nature has changed climate greatly in the past, and the ice sheet responded, growing with cooling and shrinking with warming. But, the natural climate changes were almost always much slower than the expected human-caused changes to come.

More-recent glacier tracks. Just to the north of the main flow of Jakobshavn, this piece of the Greenland ice sheet has been melting back recently, revealing bare rock or glacially deposited materials (till) still showing the marks of the former glacier motion.



The calving front of Jakobshavn. Ice flows down from the Greenland ice sheet on the left, along the arrow. On the right is the Isfjord, ocean water clogged with loose icebergs that have calved off. The next picture is taken from the helicopter, flying somewhere along the cliff where the icebergs form, perhaps near the “X”.

The cliff at the front of Jakobshavn Glacier, viewed from our helicopter. Numerous cracks are visible, and blocks of ice may break off along these in the future.

The front of Jakobshavn. Ice flows in the direction of the black arrow, left, which ends just above the ice cliff seen in the previous two pictures Two decades ago, Jakobshavn was one of the fastest glaciers on the planet, and possibly the fastest. Then, the speed doubled, to over 7 miles/year or about 4 feet/hour. (Some other fast-moving glaciers also accelerated, so there is still a competition for who is fastest.) The speed-up seems to have occurred because warming-induced melting removed a floating extension, called an ice shelf, that filled part of the fjord and, because of friction with the rocky walls, helped hold back the ice behind. The blue arrow on the right is superimposed on a large iceberg that has broken loose and is moving down the Isfjord in the direction of the arrow; 20 years ago, this would have remained attached as part of the ice shelf.

Here, a large iceberg is beginning to break free. The soon-to-be iceberg is at the end of the pink arrow, which spans the growing crack that will release the berg. The white rod with red ball, (bottom of picture) is attached to the front of the helicopter, which could fly through the crack spanned by the pink arrow.

The helicopter, flying low over icebergs in the Isfjord, carrying members of the CODEL Boxer mission.

Crevasses, up on the ice sheet near the end of Jakobshavn Glacier. The vast ice sheet spreads from the center, but funnels its flow into deep bedrock channels near the edges. Jakobshavn fills one of these, as a fast-flowing ice stream, or jet of ice, flanked by slower-moving ice. Our 8-passenger helicopter would have fit easily into these crevasses. Just as all piles tend to spread under their own weight, the ice sheet spreads and stretches, contributing to crevasse formation.

Lake in crevasse on Jakobshavn Glacier. Meltwater pools in crevasses, and helps wedge them open. Near the ice front, this helps cause icebergs to break off. Farther inland, the pressure of water in crevasses helps open them, allowing the water to drain to the bed and lubricate ice motion; new results indicate that more meltwater in a warmer world will give more lubrication, faster flow and thus sea-level rise.

Iceberg. The pink arrow points to a “blue band”, which formed when a crevasse filled with water that then re-froze. Had more water been present, or more stretching, this might have broken through to the bed, lubricating ice flow or helping break off an iceberg.

So much ice is calving off the front of Jakobshavn Glacier that the pieces choke the fjord (so it is often called the Isfjord). The mass of broken-up pieces, often mixed with frozen ocean water (sea ice) formed in the winter, is sometimes called sikkusak. Several months or longer are needed for an iceberg to be pushed down the fjord and out to sea.

Seal, in Jakobshavn Isfjord. The fjord is so clogged with ice calved from the glacier that it is sometimes hard to realize that deep seawater lies beneath. This seal, far up the fjord, is good evidence that indeed an appropriately equipped swimmer can get here.

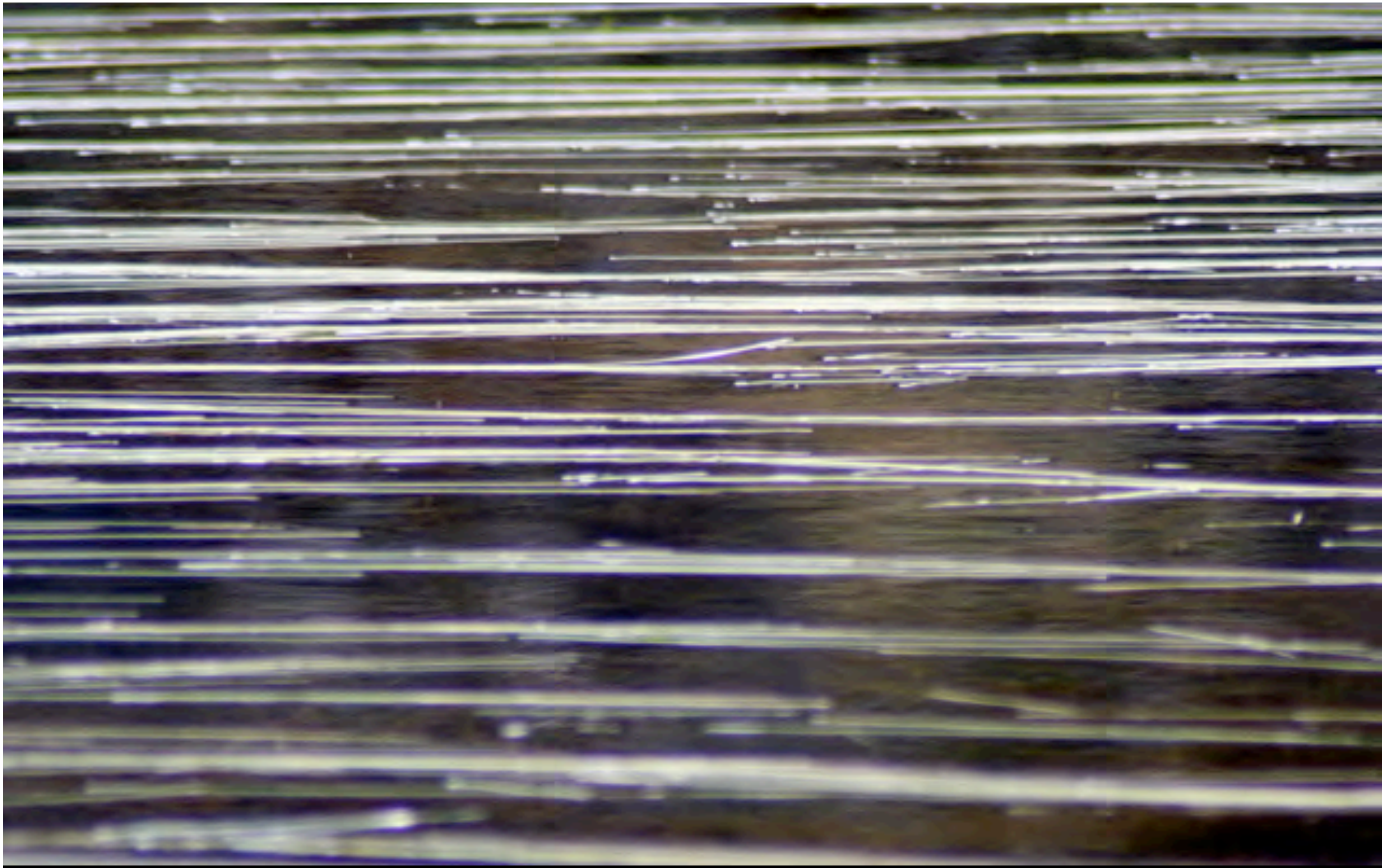
Ice is very slightly blue. Just as the thin edge of a broken piece of blue glass looks almost clear but the thicker glass shows the color, light must go through a lot of ice to show the blue. Under many circumstances the light is either absorded, or bounces off bubbles and right to your eye, before passing through enough ice to give the blue color. In some places, the bubbliness and lighting are appropriate for the light to pass through a lot of ice and then reach your eye, giving the glorious blue color. Here, blue is more evident in the cracks than on the surface.

Icebergs such as these may survive months or even years, but their days are numbered. Influenced by waves and accelerated by melting, fractures will grow until large bergs fall apart. The “bergy bits” in the water in the foreground of the picture fell off the large icebergs behind.

Most of the iceberg is below the surface; usually about 9/10 is, although this may vary a bit depending on how much air is in the ice as bubbles or filling fractures. When the light is right, it is easy to see the “root” of the iceberg disappearing into the depths, as shown here.

Icebergs in the Jakobshavn Isfjord. Fjords normally follow old weaknesses in the rocks beneath, but were deepened and widened by erosion when the glacier was bigger in the past. Glaciers pick up loose rocks or break rocks loose, and use these tools to sandpaper the rock beneath.

Fishing boat, Ilulissat. When the Greenland ice sheet was bigger, toward the end of the last ice age, the ice ended near where the icebergs sit (before that, the ice extended farther out to the west). After glaciers erode the rock beneath, they pile the eroded material around themselves. Like many other glaciers, Jakobshavn made a deep fjord with a shallow sill. The largest icebergs have difficulty getting over that sill, and tend to cluster behind it until they melt or break up enough to get out.



Aquatic “grass” stems floating in a pond. Plants grow rapidly in the 24-hour sun of the Arctic summer, but after death decay slowly in the cold of the permafrost. Over time, this tends to make Arctic soils quite carbon-rich. Greenland’s soils are often thin or absent but are carbon-rich (often peat) in some places, and much thicker carbon-rich soils occur in other parts of the Arctic. There is concern that warming will cause Arctic soils to lose much of their carbon to the atmosphere as carbon dioxide, amplifying the warming.

Isfjord, Jakobshavn. Archaeological sites near where this picture was taken show that humans have settled here for over 4000 years, often living in peat-walled houses and relying on the sea, hunting seals (the Saqqaq people), then focusing more on walrus (the Dorset) and later whales (the Thule people) as technologies improved.

Icebergs. From Ilulissat.

Fishing boat, Isfjord. Because icebergs sometimes roll over or break apart, care is required in navigating nearby, to avoid being hit by falling or by rising ice, or swamped by a wave (tsunami) generated by moving ice.

Fishing boats, Isfjord. Seawater freshened by melting bergs tends to float on top of the sea in many fjords, keeping nutrient-laden waters deeper and suppressing biological productivity. However, where the meltwater is actively rising from the deep keel of a melting berg, seawater may be dragged along, stimulating productivity. Fishers in these waters must master a complex environment, which is now changing rapidly.

Ilulissat may have more dogs than people. Winter travel on the frozen waters of Disko Bay for hunting or other purposes has long been favored, with the flat surface making travel much easier than on the rocky hills ashore. Warming has reduced the frozen-up season, however, casting doubt on the economic viability of maintaining this traditional way of life.