The world has a third pole – and it's melting quickly

The Observer

Himalayas: An IPCC report says two-thirds of glaciers on the largest ice sheet after the Arctic and Antarctic are set to disappear in 80 years

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The Mingyong glacier at the foot of Khawa Karpo. Photograph: Tao Images Limited/Alamy Stock Photo

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any moons ago in Tibet, the Second Buddha transformed a fierce *nyen* (a malevolent mountain demon) into a *neri* (the holiest protective warrior god) called Khawa Karpo, who took up residence in the sacred mountain bearing his name. Khawa Karpo is the tallest of the Meili mountain range, piercing the sky at 6,740 metres (22,112ft) above sea level. Local Tibetan communities believe that conquering Khawa Karpo is an act of sacrilege and would cause the deity to abandon his mountain home. Nevertheless, there have been several failed attempts by outsiders – the best known by an international team of 17, all of whom died in an avalanche during their ascent on 3 January 1991. After much local petitioning, in 2001 Beijing passed a law banning mountaineering there.

However, Khawa Karpo continues to be affronted more insidiously. Over the past two decades, the Mingyong glacier at the foot of the mountain has dramatically receded. Villagers blame disrespectful human behaviour, including an inadequacy of prayer, greater material greed and an increase in pollution from tourism. People have started to avoid eating garlic and onions, burning meat, breaking vows or fighting for fear of unleashing the wrath of the deity. Mingyong is one of the world's fastest shrinking glaciers, but locals cannot believe it will die because their own existence is intertwined with it. Yet its disappearance is almost inevitable.

Khawa Karpo lies at the world's "third pole". This is how glaciologists refer to the Tibetan plateau, home to the vast Hindu Kush-Himalaya ice sheet, because it contains the largest amount of snow and ice after the Arctic and Antarctic – about 15% of the global total. However, a quarter of its ice has been lost since 1970. This month, in a long-awaited special report on the cryosphere by the Intergovernmental Panel on Climate Change (IPCC), scientists will warn that up to two-thirds of the region's remaining glaciers are on track to disappear by the end of the century. It is expected a third of the ice will be lost in that time even if the internationally agreed target of limiting global warming by 1.5C above pre-industrial levels is adhered to.

Whether we are Buddhists or not, our lives affect, and are affected by, these tropical glaciers that span eight countries. This frozen "water tower of Asia" is the source of 10 of the world's largest rivers, including the Ganges, Brahmaputra, Yellow, Mekong and Indus, whose flows support at least 1.6 billion people directly – in drinking water, agriculture, hydropower and livelihoods – and many more indirectly, in buying a T-shirt made from cotton grown in China, for example, or rice from India.

Joseph Shea, a glaciologist at the University of Northern British Columbia, calls the loss "depressing and fear-inducing. It changes the nature of the mountains in a very visible and profound way."

Yet the fast-changing conditions at the third pole have not received the same attention as those at the north and south poles. The IPCC's fourth assessment report in 2007 contained the erroneous prediction that all Himalayan glaciers would be gone by 2035. This statement turned out to have been based on anecdote rather than scientific evidence and, perhaps out of embarrassment, the third pole has been given less attention in subsequent IPCC reports.

There is also a dearth of research compared to the other poles, and what hydrological data exists has been jealously guarded by the Indian government and other interested parties. The Tibetan plateau is a vast and impractical place for glaciologists to work in and confounding factors make measurements hard to obtain. Scientists are forbidden by locals, for instance, to step out on to the Mingyong glacier, meaning they have had to use repeat photography to measure the ice retreat.

In the face of these problems, satellites have proved invaluable, allowing scientists to watch glacial shrinkage in real time. This summer, Columbia University researchers also used declassified spy-satellite images from the cold war to show that third pole ice loss has accelerated over this century and is now roughly double the melt rate of 1975 to 2000, when temperatures were on average 1C lower. Glaciers in the region are currently losing about half a vertical metre of ice per year because of anthropogenic global heating, the researchers concluded. Glacial melt here carries significant risk of death and injury – far more than in the sparsely populated Arctic and Antarctic – from glacial lake outbursts (when a lake forms and suddenly spills over its banks in a devastating flood) and landslides caused by destabilised rock. Whole villages have been washed away and these events are becoming increasingly regular, even if monitoring and rescue systems have improved. Satellite data shows that numbers and sizes of such risky lakes in the region are growing. Last October and November, on three separate occasions, debris blocked the flow of the Yarlung Tsangpo in Tibet, threatening India and Bangladesh downstream with flooding and causing thousands to be evacuated.

An artificial glacier in Ladakh, created by engineer and farmer Chewang Norphel. Photograph: Chewang Norphel

One reason for the rapid ice loss is that the Tibetan plateau, like the other two poles, is warming at a rate up to three times as fast as the global average, by 0.3C per decade. In the case of the third pole, this is because of its elevation, which means it absorbs energy from rising, warm, moisture-laden air. Even if average global temperatures stay below 1.5C, the region will experience more than 2C of warming; if emissions are not reduced, the rise will be 5C, according to a report released earlier this year by more than 200 scientists for the Kathmandu-based International Centre for Integrated Mountain Development (ICIMOD). Winter snowfall is already decreasing and there are, on average, four fewer cold nights and seven more warm nights per year than 40 years ago. Models also indicate a strengthening of the south-east monsoon, with heavy and unpredictable downpours. “This is the climate crisis you haven’t heard of,” said ICIMOD’s chief scientist, Philippus Wester.

There is another culprit besides our CO_2 emissions in this warming story, and it’s all too evident on the dirty surface of the Mingyong glacier: black carbon, or soot. A 2013 study found that black carbon is responsible for 1.1 watts per square metre of the Earth’s surface of extra energy being stored in the atmosphere (CO_2 is responsible for an estimated 1.56 watts per square metre). Black carbon has multiple climate effects, changing clouds and monsoon circulation as well as accelerating ice melt. Air pollution from the Indo-Gangetic Plains – one of the world’s most polluted regions – deposits this black dust on glaciers, darkening their surface and hastening melt. While soot landing on dark rock has little effect on its temperature, snow and glaciers are particularly vulnerable because they are so white and reflective. As glaciers melt, the surrounding rock crumbles in landslides, covering the ice with dark material that speeds melt in a runaway cycle. The Everest base camp, for instance, at 5,300 metres, is now rubble and debris as the Khumbu glacier has retreated to the icefall.

The immense upland of the third pole is one of the most ecologically diverse and vulnerable regions on Earth. People have only attempted to conquer these mountains in the last century, yet in that time humans have subdued the glaciers and changed the face of this wilderness with pollution and other activities. Researchers are now beginning to understand the scale of human effects on the region – some have experienced it directly: many of the 300 IPCC cryosphere report authors meeting in the Nepalese capital in July were forced to take shelter or divert to other airports because of a freak monsoon.

But aAside from such inconveniences, what do these changes mean for the 240 million people living in the mountains? Well, in many areas, it has been welcomed. Warmer, more pleasant winters have made life easier. The higher temperatures have boosted agriculture – people can grow a greater variety of crops and benefit from more than one harvest per year, and that improves livelihoods. This may be responsible for the so-called Karakoram anomaly, in which a few glaciers in the Pakistani Karakoram range are advancing in opposition to the general trend. Climatologists believe that the sudden and massive growth of irrigated agriculture in the local area, coupled with unusual topographical features, has produced an increase in snowfall on the glaciers which currently more than compensates for their melting.

Elsewhere, any increase in precipitation is not enough to counter the rate of ice melt and places that are wholly reliant on meltwater for irrigation are feeling the effects soonest. "Springs have dried drastically in the past 10 years without meltwater and because infrastructure has cut off discharge," says Aditi Mukherji, one of the authors of the IPCC report.

A man tends a vegetable plot in the Karakoram range. Photograph: Luis Dafos/Getty Images

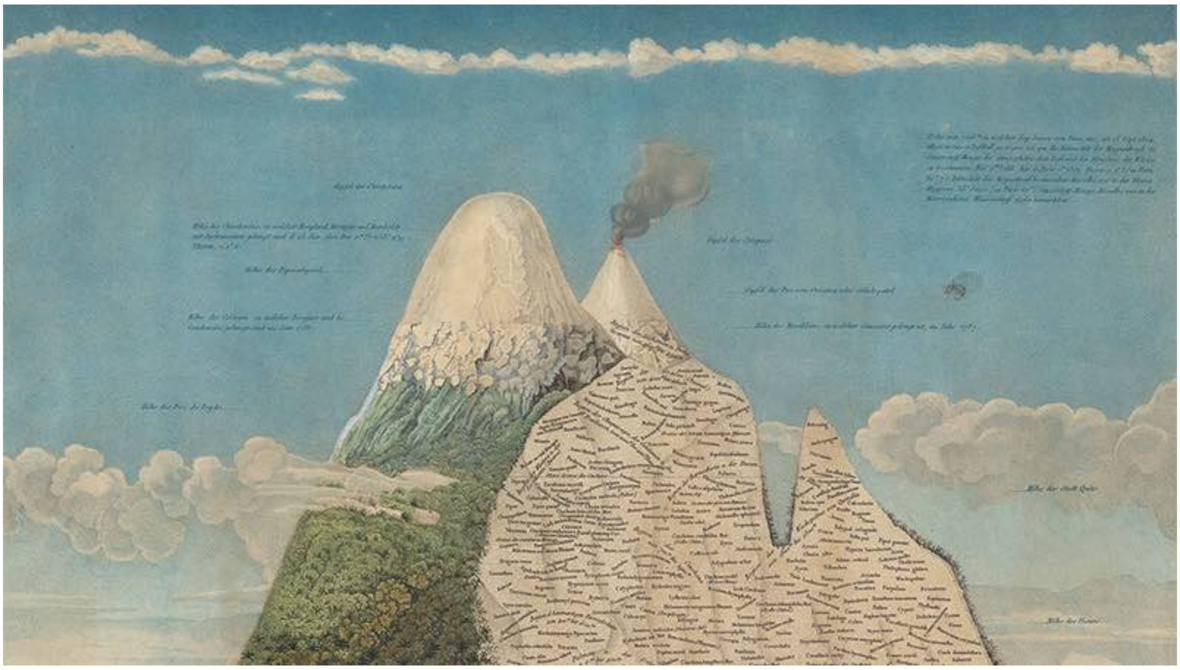
Known as high-altitude deserts, places such as Ladakh in north-eastern India and parts of Tibet have already lost many of their lower-altitude glaciers and with them their seasonal irrigation flows, which is affecting agriculture and electricity production from hydroelectric dams. In some places, communities are trying to geoengineer artificial glaciers that divert runoff from higher glaciers towards shaded, protected locations where it can freeze over winter to provide meltwater for irrigation in the spring.

Only a few of the major Asian rivers are heavily reliant on glacial runoff – the Yangtze and Yellow rivers are showing reduced water levels because of diminished meltwater and the Indus (40% glacier-fed) and Yarkand (60% glacier-fed) are particularly vulnerable. So although mountain communities are suffering from glacial disappearance, those downstream are currently less affected because rainfall makes a much larger contribution to rivers such as the Ganges and Mekong as they descend into populated basins. Upstream-downstream conflict over extractions, dam-building and diversions has so far largely been averted through water-sharing treaties between nations, but as the climate becomes less predictable and scarcity increases, the risk of unrest within – let alone between – nations grows.

Towards the end of this century, pre-monsoon water-flow levels in all these rivers will drastically reduce without glacier buffers, affecting agricultural output as well as hydropower generation, and these stresses will be compounded by an increase in the number and severity of devastating flash floods. “The impact on local water resources will be huge, especially in the Indus Valley. We expect to see migration out of dry, high-altitude areas first but populations across the region will be affected,” says Shea, also an author on the ICIMOD report.

As the third pole’s vast frozen reserves of fresh water make their way down to the oceans, they are contributing to sea-level rise that is already making life difficult in the heavily populated low-lying deltas and bays of Asia, from Bangladesh to Vietnam. What is more, they are releasing dangerous pollutants. Glaciers are time capsules, built snowflake by snowflake from the skies of the past and, as they melt, they deliver back into circulation the constituents of that archived air. Dangerous pesticides such as DDT (widely used for three decades before being banned in 1972) and perfluoroalkyl acids are now being washed downstream in meltwater and accumulating in sediments and in the food chain.

Ultimately the future of this vast region, its people, ice sheets and arteries depends – just as Khawa Karpo’s devotees believe – on us: on reducing our emissions of greenhouse gases and other pollutants. As Mukherji says, many of the glaciers that haven’t yet melted have effectively “disappeared because in the dense air pollution, you can no longer see them”.



Alexander von Humboldt's 1807 *Tableau Physique* mapped vegetation onto fanciful versions of the volcanoes Chimborazo and Cotopaxi. DESIGNED BY A. VON HUMBOLDT/DRAWN BY SCHÖNBERGER AND TURPIN/ENGRAVED BY BOUQUET/TYPEFACE BY L. AUBERT/PRINTED BY LANGLOIS/WIKIMEDIA COMMONS

Global warming has made iconic Andean peak unrecognizable

By Tim Appenzeller Sep. 11, 2019 , 4:15 PM

On 23 June 1802, German geographer Alexander von Humboldt and his companions could climb no higher. Plagued by altitude sickness, their gloveless hands bloodied from jagged handholds, and their boots sodden, they faced a final obstacle in their quest to climb Chimborazo, a 6268-meter-high volcano in Ecuador then thought to be the world's highest mountain. The clouds briefly parted, revealing the summit—and a chasm barring their way. They had reached "a place higher than all others that men had reached on the backs of the mountains," Humboldt boasted later. But they had to turn back, some 400 vertical meters short of their goal.

In the end, Humboldt spun his defeat on Chimborazo into a triumph that cemented his reputation as the era's superstar scientist and explorer—and his legacy. Not long after his descent from the mountain, he sketched a spectacular diagram that used the slopes of Chimborazo to depict a concept that had crystallized during his climb: that climate is an organizing principle of life, shaping the distinct communities of plants and animals found at different altitudes and latitudes. The diagram—Humboldt called it his *Tableau Physique*—has become what one recent paper described as "an iconic milestone, almost a foundation myth, in the history of ecology."

Today, the idea born on Chimborazo—that the physical environment shapes life's grand patterns—is giving scientists an intellectual framework for understanding a phenomenon Humboldt himself could not have anticipated: how human-driven climate change is transforming life.

Tropical mountains are ideal stages for watching climate change unfold. They compress many climates into a small space, as Humboldt wrote in his *Essay on the Geography of Plants*: "On this steep surface climbing from the ocean level to the perpetual snows, various climates follow one another and are superimposed, so to speak." Now, global warming is quickly reshuffling those montane climates. And few peaks record the impact of human-driven climate change more vividly than Chimborazo itself. The massive volcano, which last erupted 1500 years ago, rises just 1° south of the equator. On the peak's eastern slopes, moisture from the Amazon Basin next door—plus temperatures that rarely drop below freezing except at the highest elevations—nurture grassland, bogs, and springy cushions of moss and dwarf alpine plants, all highly sensitive to climate change. Below the summit sprawl 17 small glaciers, bellwethers of global warming and a crucial water source for tens of thousands of people living at lower elevations.

As a result, the volcano has again become a draw for researchers. Some have tracked how fast the plants that Humboldt observed are migrating upward as temperatures rise. Other scientists are probing how retreating glaciers and shifting vegetation may be altering the flow of water from the mountain to thirsty communities below. Together, those studies are mapping the interplay of plants, people, and an environment that is now changing because of humanity's impact.

The modern research adopts Humboldt's holistic approach, repurposed for an era of climate change, says ecologist Priscilla Muriel of the Pontifical Catholic University of Ecuador in Quito. "Data is not just data; you have to actually go out and look at things, observe things, and try to get a feel of what nature actually is."

IN JUNE, in a lush valley at 4000 meters—more than two vertical kilometers below Chimborazo's summit—geographer Jeff La Frenierre stood waist deep in a concrete irrigation channel flowing with turbid water. Clad in fishing waders, he dipped an instrument into the torrent, measuring its velocity to calibrate an automated stream gauge nearby. "This is all the water coming out of our study area," he said—the full harvest of the melting Reschreiter Glacier, Chimborazo's largest, plus the rain and snow that fall in the same 7.5-square-kilometer watershed.

For the past decade, La Frenierre, who teaches at Gustavus Adolphus College in St. Peter, Minnesota, has visited Chimborazo once or twice a year to study how climate change is affecting its glaciers, stream flow, and groundwater. He is astonished at how fast the ice is succumbing.

Flows are dwindling in irrigation canals carrying water from Ecuador's volcanoes. Geographer Jeff La Frenierre (left) and graduate student Leah Nelson (right) are investigating the role of shrinking glaciers. EVAN TAYLOR/GUSTAVUS ADOLPHUS COLLEGE

Chimborazo's glaciers have lost a

bout 20% of their surface area since the 1980s, and the 2.5-square-kilometer Reschreiter has retreated by more than 1 kilometer, he says. Leonardo Punina Tuolombo, who grew up in an Indigenous community nearby, has watched it happen. "All the time, the glacier moves higher," says Punina Tuolombo, 37, who guides and outfits hikers and has a small farm—five cows and fields of garlic—at an elevation of 4200 meters. "I remember when I was a boy, the glacier was tremendous," he says. "Now, it's rock."

The waning of the ice has made the mountain even more treacherous than in Humboldt's day. Rocks once cemented into place by ice now tumble down its slopes, endangering climbers; one guide died this past spring. Lakes of meltwater that accumulate at the foot of the glaciers periodically burst their banks, unleashing floods that sweep mud and boulders into the valleys below. "Many lakes are collapsing," Punina Tuolombo says. In 2007, he watched a meltwater flood race down the mountain: "We saw rocks falling, people climbing hills for safety."

Similar stories are unfolding throughout the tropics. "The story of loss of glaciers is pretty common," says Bryan Mark, a geographer at Ohio State University in Columbus who has chronicled the retreat of ice and its impact on water supplies in the Andes of Peru. "It's a warming thing." High tropical mountains are among the fastest-warming regions of the planet, by about one-tenth of a degree Celsius per decade. One factor is a feedback loop familiar from the Arctic: As reflective ice and snow vanish, they expose darker surfaces that absorb more solar radiation, amplifying the warming. Changes in moisture are also speeding glacier loss. In some places, dry seasons are lasting longer, starving the glaciers of snowfall; elsewhere, precipitation that once fell as snow more often comes down as rain. And humidity is rising, which transfers heat more efficiently to the ice.

Those processes are converting Chimborazo's gleaming ice to a sodden, pitted moonscape. Seven years ago, La Frenierre planted a stake in the tongue of the Reschreiter Glacier to measure the rate of melting; this summer he found it bent, lying on bare gravel. The nearest ice was 260 meters away, above a sheer cliff.

AS THE ICE RETREATS, farmers are moving upward. When Humboldt visited Chimborazo in 1802, the farm fields ended at about 3600 meters. Now, population growth and a more benign climate have pushed agriculture hundreds of meters upslope. Dark beds of potato and other crops are encroaching on the grasslands above 4000 meters, where frosts have become rarer.

Meanwhile, rainfall has become less predictable, farmers say. At lower altitudes, irrigation can make the difference between two harvests a year—enough to survive as a full-time farmer—and one. But in the irrigation canal that drains La Frenierre's study area, annual peak flows have dropped by as much as half since the early 1980s. That decrease has strained agreements that divide the water among farming communities. "Eighty percent of the time, there's not enough water to supply the allocation," he says. As a result, "You're already starting to see conflicts between upstream users and downstream users."

Farmers grow potatoes and other crops above 4000 meters on Ecuador's peaks. For many, irrigation—supplied in part by dwindling ice—is crucial. EVAN TAYLOR/GUSTAVUS ADOLPHUS COLLEGE

La Frenierre thinks the plight of the Reschreiter Glacier, melting away 6 kilometers up the valley from the irrigation intake, is one reason. In the early years of retreat, a glacier produces a surge of meltwater, swelling streams. But as the ice shrivels, the system passes a tipping point and the flow of meltwater declines. Mark has observed that effect in Peru; on Chimborazo, too, "We could have passed the threshold to lower runoff," La Frenierre says.

To gauge the importance of that runoff, La Frenierre, hydrologist G.-H. Crystal Ng of the University of Minnesota in Minneapolis, and their colleagues do a kind of watershed accounting. They tally the water entering their study area—rain, snow, and glacial meltwater—as measured by automated weather stations and surveys of the shrinking ice. Then, the researchers enter those data into computer models and adjust the models to match the ebb and flow of water out of the valley, recorded by their automated stream gauges.

Water draining straight from the melting glacier can vary over just a few hours, depending on the weather. The flow is "really flashy, really peaky," Ng says. But the amount of groundwater seeping into the stream varies more slowly, over time scales of a week or so. From the tempo at which stream flow rises and falls, the models can disentangle how much of the water runs straight off the ice and how much originates as groundwater, which is fed largely by precipitation.

Ng's team has also analyzed the water's levels of dissolved minerals, mainly magnesium and calcium. They can be used to trace groundwater, which picks up the minerals as it percolates through soil and bedrock. Together, the modeling and dissolved minerals confirm that only a fraction of the flow into the irrigation system, perhaps 10%, originates directly from the glacier. But it is a crucial 10%. "The loss of 5% to 10% of your water from losing the glacier is going to only enhance the shortage," La Frenierre says. Downstream users "can't afford to lose any more water," Ng adds.

Chimborazo’s largest glacier, the Reschreiter, has retreated by more than one kilometer since the 1980s, leaving a sodden, pitted landscape. JORGE GARCIA, UNIVERSITY OF SAN JUAN

Another phenomenon is contributing to the channel's shrinking flow, and it, too, may be linked—indirectly—to glacier loss. Farther up the valley, labor cooperatives from villages on Chimborazo's drier slopes have built dozens of small concrete dams to capture water from springs. The water is diverted into pipes and canals that carry it across the flanks of the mountain and down to farms and villages, whose own springs are mysteriously drying up.

Ng and La Frenierre are investigating a possible explanation: that some of the meltwater from Chimborazo's glaciers doesn't drain directly into streams but instead percolates down into the porous volcanic rock at the base of the ice. The water then circulates underground, adding to the groundwater that feeds the wells and springs in farming communities at lower elevations. "The big question is how much of the groundwater is glacial," La Frenierre says. "That's what we're trying to quantify."

So far, the computer models suggest infiltrating melt contributes about 20% of the groundwater in their study area. If that result holds up, glacier retreat on other flanks of the mountain could be to blame for failing springs at lower elevations—which is spurring the communities to build still more water diversions that further reduce the flow in the irrigation channel.

More diversions could amplify the tensions over water. Already, La Frenierre says, "You tread very carefully when you ask [local people] about water supplies." To aid planning and defuse future conflicts, he and his colleagues hope to build a model that would forecast how glacial retreat will make water even scarcer and less reliable for downstream users—not just on Chimborazo, but on glacierized mountains everywhere.

To make their model fully realistic, however, the researchers need to include one more claimant on the mountain's water: the ranks of vegetation that Humboldt depicted—and that are now moving upslope.

On Cayambe, an Ecuadorian volcano 300 kilometers from Chimborazo, Daniel Stanton, Jeff La Frenierre, and Leah Nelson (left to right) collect data on glacier melting. EVAN TAYLOR/GUSTAVUS ADOLPHUS COLLEGE

ON CHIMBORAZO, gray-green lichens and pillows of moss are colonizing the rocks and gravel recently bared by retreating ice. Here and there, tabletop-size islands of brighter green stand out, each centered on a small mound of droppings deposited by vicuñas. The small, llamalike creatures, introduced to Chimborazo decades ago from farther south in the Andes, defecate on communal dung heaps, supplying a boon of nitrogen for plants.

Newly verdant slopes are easy to see on many Andean peaks. But Humboldt's data, compiled on his *Tableau Physique*, offer something much rarer: a chance to reconstruct a 200-year history of how plants have migrated upward. During his climbs, Humboldt stopped periodically to take elevation readings with a fragile glass barometer and, with his botanist companion Aimé Bonpland, to record and collect plants. The result is a record of mountain biogeography from the beginning of the Industrial Revolution—a unique baseline for gauging the changes since then.

A group led by ecologist Naia Morueta-Holme, then at Aarhus University in Denmark, was the first to try to tap those data. Combing the *Tableau* and other records Humboldt compiled, the team found information on the altitude ranges of some 50 alpine plant varieties. Then, they climbed much of the way up Chimborazo themselves to see where those plants now grow.

Their resurvey, published in the *Proceedings of the National Academy of Sciences* (*PNAS*) in 2015, detailed a startling transformation. Whereas Humboldt had recorded an upper limit for seed plants of 4600 meters, Morueta-Holme and her team found pioneers as high as 5185 meters. Other, lower-living species—showy gentians, a spiky aster relative called *Chuquiraga*, purple lupines—had moved upslope by an average of more than 500 meters since 1802. It was eye-catching evidence that climate change has upended the world Humboldt mapped.

Botanist Daniel Stanton studies how vegetation on Chimborazo in Ecuador and other tropical peaks captures water—and how the upward migration of plants as the climate warms may worsen water shortages. Mosses are among the first plants to colonize newly bared slopes as glaciers retreat. EVAN TAYLOR/GUSTAVUS ADOLPHUS COLLEGE

Not everyone was convinced that the data displayed in the *Tableau* were reliable enough to support those conclusions. Humboldt himself warned against expecting high precision from what was as much a work of art as of science, writing, "in a work of this kind, one must consider two conflicting interests, appearance and exactitude." This year, a team including Muriel scrutinized Humboldt's diaries and collections, concluding that his *Tableau* was not a faithful record of what grew on Chimborazo 200 years ago.

For one thing, the researchers noted, Humboldt spent just a few hours on the highest slopes of Chimborazo, and he and Bonpland collected no plants above 3600 meters. They also sampled less systematically than modern botanists. "Humboldt never has precise information about ranges. He and Bonpland probably collected plants when they first saw them," says Pierre Moret of Toulouse University in France, lead author of the paper, published this year in *PNAS*.

What's more, Moret and his co-authors found that much of the data Humboldt displayed on the slopes of Chimborazo actually came from another volcano, 5700-meter Antisana, 130 kilometers to the northeast. He and Bonpland spent 4 days there, collecting and recording dozens of species. Humboldt mapped the data onto Chimborazo because, well, Chimborazo was more famous.

"It's definitely messy," says Morueta-Holme, who is now at the University of Copenhagen. "We were sticking with broadscale patterns."

Moret's team decided to do its own survey of those patterns—not on Chimborazo, but on Antisana, the source of most of Humboldt's data. In 2017, the researchers systematically mapped the current ranges of 31 species there. For most, the imprecision of the *Tableau* made it hard to calculate just how far upslope those plants have moved. But for one species, a silvery leafed shrub called *Senecio nivalis*, Bonpland had clearly recorded a maximum altitude of 4860 meters, right where Antisana's permanent snow began. The plant now grows above 5100 meters, having climbed more than 200 vertical meters, in step with the rising snow line.

That's only half of the 500 meters Morueta-Holme and colleagues originally calculated, but still a dramatic shift upslope. "I'll continue to believe the patterns, but not the precise numbers," says Daniel Stanton, a botanist from the University of Minnesota in St. Paul, who works with Ng and La Frenierre. "Whether it's 300 meters or 500 meters, we're still talking about substantial change."

During fieldwork on Chimborazo, researchers camp at 4400 meters near ancient glacial moraines. T. APPENZELLER/*SCIENCE*

As the vegetation marches upward, it may be adding to the strain on water resources—in particular the groundwater likely coming from the melting glaciers, Stanton and Ng say. Plants can tap deep water and release it into the atmosphere as water vapor, which means the greening of the mountain could exacerbate water shortages in the settlements below. To forecast water flows, Ng says, "You need to account for [both glacier loss] and vegetation migrating upslope and transpiring."

The researchers hope to fine-tune estimates of how much groundwater plants are intercepting by taking samples—especially of deep-rooted, woody plants such as *Polylepis*, the Andean "fairy trees" with twisting limbs and papery bark. The plan is to analyze water flowing in the xylem, the water-carrying layers of wood, for tracers suggesting it came from the melting glacier. If the amounts are significant, the vegetation zones that Humboldt mapped will join glaciers, streams, and groundwater in a complex hydrological interplay, ultimately driven by global warming.

CLIMATE CHANGE and other human impacts may have made Humboldt's *Tableau* unrecognizable, but he remains a vivid presence for scientists following in his footsteps—including Sisimac Duchicela, who grew up in Quito, 200 kilometers north of Chimborazo, and is working on her Ph.D. at the University of Texas in Austin. In a bid to preview warming impacts, she and colleagues are doing field experiments on Pichincha, another Ecuadorian volcano Humboldt climbed. They have enclosed small patches of high-altitude vegetation in clear plastic, creating a focused, artificial greenhouse effect.

As Duchicela monitors those microcosms, she remembers how Humboldt approached those same mountains: "by looking at everything—at the little things and the big things and how they connect to each other. That part," she adds, "was particularly inspiring for me."