INSIGHTS

PERSPECTIVES

Gokyo lakes are the world's highest freshwater lake system located in Nepal, Asia. The beautiful, pristine, and sacred lake is vulnerable to climate change–induced natural hazards.

PHOTO: FENG WEI PHOTOGRAPHY/GETTY IMAGES

HYDROLOGY

Preparing for floods on the Third Pole

Satellite-based real-time monitoring is needed for Himalayan glacial catchments

By **Tanuj Shukla** and **Indra S. Sen**

The mountains that include the Himalayan and adjacent ranges are the highest on Earth and have an average elevation of >4000 m and an area of ~595,000 km^2. This region is also called the Third Pole or the Asian water tower because it has the largest ice mass outside the polar regions. Increasing temperatures and human interventions have added stress on the region's hydrological sensitivity and have increased the risks of major flood events.

Over the next 100 years, an estimated 1.5°C of warming will likely be enhancing the melting rates of glaciers, which have already been made fragile by climate change (*1*). This situation is evident from the accelerating glacier-ice mass loss, permafrost degradation, increasing extreme temperature and precipitation events, landslides, rapid snowmelt, and a substantial shift in seasonal riverine water supply (*2*, *3*). Ad-

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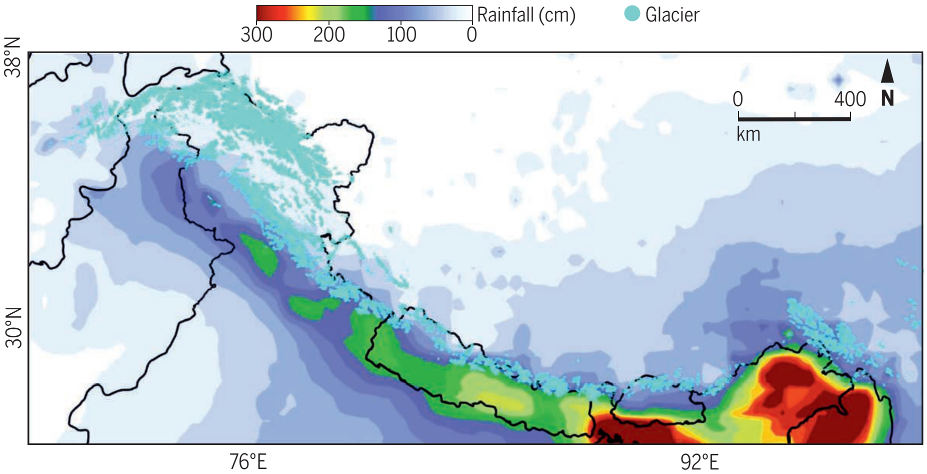
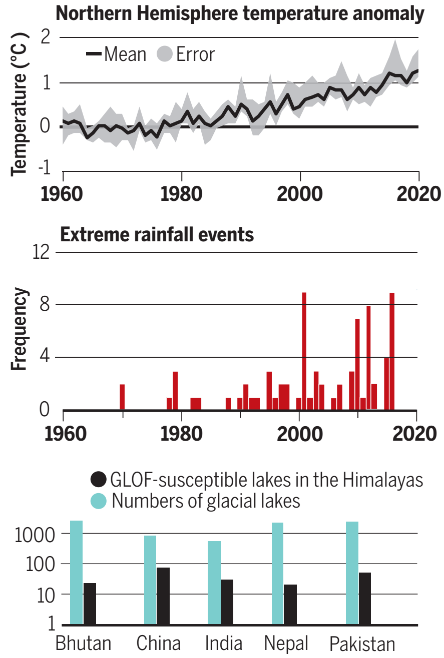
Rainfall in the Himalayas

Glacial lake areas [glacier data from the Randolph Glacier Inventory (*6*)] are affected by the regional rainfall, which has had local variations from 2000 to 2015 (data source: https://disc.gsfc.nasa.gov/datasets/TRMM_3B42_Daily_7/summary) (left). The increasing temperature in the Northern Hemisphere (top right) (data source: https://data.giss.nasa.gov/gistemp) is correlated with an increased number of extreme rainfall events (middle right) (*10, 11*) and an expansion in the number of glacial lakes, some that are susceptible to glacial lake outburst floods (GLOFs), across the region (bottom right) (*12*).





ditionally, the Indian Summer Monsoon is responsible for 300 cm year^{-1} of annual rainfall over the south-facing slopes of the Himalayas (see the figure). All of these observations make the region prone to multiple natural hazards, including the increased risks of major flood events (*3*, *4*). Direct human interventions on the rivers, such as the construction of hydroelectric power plants, change the risk profile in other ways (*5*).

Increasing concern has been centered around glacial lake outburst floods (GLOFs) and cloudburst events. GLOFs occur when either a natural dam bursts or the glacial lake level suddenly increases. These events are usually a result of cloudbursts, where torrential precipitation of >100 mm hour^{-1} occurs over a geographical region of ~25 km^2. These extreme events have increased in recent decades, as have the catastrophes associated with them (*6*). For example, the GLOF event in the Chorabari glacier valley (30°44′51.26′′ N, 79°03′38.79′′ E; 3808 m above sea level) in 2013 left behind a death toll of more than 5000 people and a shocking trail of devastation in the Mandakini River Valley. Unfortunately, more lake-breaching events are waiting to unfold because new lakes are continuously forming and the existing ones are expanding in the glaciated Himalayan valleys. Forty-one high-altitude lakes appeared in the Eastern Himalayan region alone during the past 50 years, and the existing lakes in the Third Pole region have undergone a 50% expansion. The lake area has rapidly expanded, at a rate of 14.44 km^2 year^{-1} between 1976 and 2018 (*7*). As a result, it is likely that the number, extent, and impacts of lake-breaching events in the Himalayas will increase in the near future.

The surge of meltwater in mountain streams is most commonly caused by cloudburst events during the monsoon season (June–July–August) time frame. However, the recent (7 February 2021), sudden surge of meltwater in the river tributary of the Ganga, Dhauli Ganga, during the dry season suggests that this time frame needs to be expanded. The catastrophe in the upper Dhauli Ganga basin is linked to processes other than precipitation events, such as snow avalanches, rock landslides, or other unidentified drivers. We therefore need to rethink the idea that cloudbursts and rainfall are the only drivers of a meltwater surge in the Himalayan region. Determining all of the potential major and minor drivers behind sudden surges of meltwater into headwater streams is vital for understanding the hazard profile of the region.

As we improve our understanding of glacial hydrology, different hypotheses will emerge. However, the most pressing need is to delve deep into mitigation strategies as risks of meltwater surges increase as a result of climate change and human-induced factors. Mitigation strategies should involve engineering solutions, such as the construction of flood-control reservoirs; structures to divert water from high-impact areas to alternative locations; rainwater detention basins; the construction of dams, dikes, and embankments; the adoption of terraces and other good farming practices to reduce the rates of hillslope runoff; and the building of structures and development of techniques to stabilize mountain slopes to reduce landslides and mudflows. Together with these structural solutions, the community needs to be made aware of the causes and drivers of mountain hydrology through public awareness programs, training, and education. This may allow for a citizen-science approach for some flood risk–management measures to be implemented. Many of these efforts have already been implemented over the past few decades (*8*), but the magnitude of these flooding events requires a more advanced adaptive measure. In particular, an effective early warning system that would warn local communities of impending flood danger is urgently needed.

As a result, equal emphasis should be given to developing a network of hydrometeorological, seismic stations and landslide-detection systems with telemetry capability to build a data-driven decision-support system. Particularly, data from the weather stations that record heavy rainfall events, ultrasonic and radar-based sensors that monitor water storage and discharge in lakes and streams, geophones that detect debris flow, and advanced avalanche-mapping technology should be transmitted in real time to support a decision system to warn local communities of the impending danger.

The biggest challenge for this strategy is the lack of cellular connectivity in the

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remote Himalayan region that prevents telemetry support, rendering it unavailable. Instead, telemetry-based monitoring of the glacierized Himalayan catchment using satellite systems (e.g., the Narrowband Internet of Things) is needed to take timely actions during the next hydrological disaster. The integration of monitoring devices with satellite networks will not only provide telemetry support in remote locations that lack complete cellular connectivity but will also provide greater connectivity coverage in the cellular dead zones in extreme topographies such as valleys, cliffs, and steep slopes.

Real-time data would help to develop a strong network of early flood warning systems in the glacierized catchment of the Himalayas. Real-time monitoring technologies would not only help to predict and warn of the impending danger and prevent loss of life, but the availability of real-time data would allow scientists to monitor the performance of the installed instruments remotely and take timely actions against any instrument malfunction, preventing the loss of vital data. Therefore, these enriched datasets will help us to better understand the effects of climate change on the Third Pole, which is often regarded as a "white spot" on the global map—indicating the presence of very limited continuous field hydrometeorological data (*9*). ■

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QUANTUM GASES

The Weyl side of ultracold matter

Ultracold gases in optical lattices provide control and tunability for the exploration of Weyl semimetal physics

By **Nathan Goldman**[1] and **Tarik Yefsah**[2]

The discovery of Weyl semimetals in 2015 was a breakthrough in the modern history of quantum matter, connecting relativistic phenomena predicted in particle physics with unusual topological properties of the solid state (*1*). This connection originates from the peculiar band structure of Weyl materials. In general, the band structure of a solid governs which energies are accessible to an electron moving with a given momentum. In Weyl semimetals, energy bands touch at singular points (the Weyl nodes), around which energy has a linear dependence on momentum *k*, reminiscent of relativistic elementary particles. On page 271 of this issue, Wang *et al*. (*2*) realized Weyl-type band structures for ultracold atoms with a high degree of control and tunability. This work paves the way for the exploration of the properties of Weyl-type band structures with a bottom-up, tunable approach and incremental complexity.

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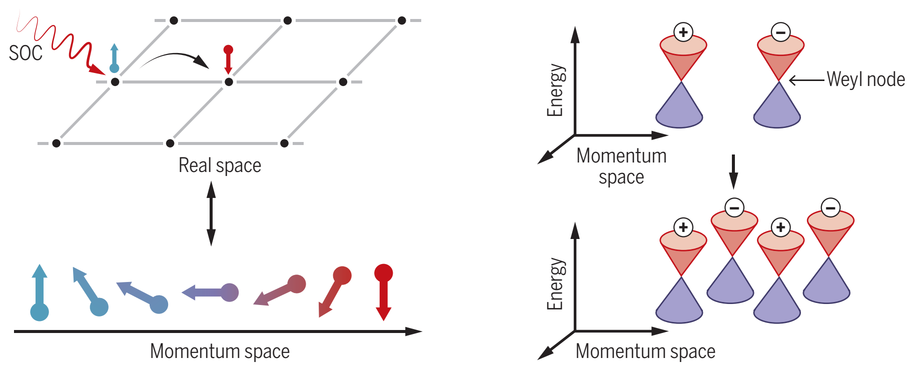
Whenever a concept of relativity finds an echo in the realm of quantum materials, it triggers a wave of astonishment and excitement. Indeed, relativistic phenomena are naturally linked to high-energy physics. The excitement comes from the possibility of bringing to reality predictions that otherwise may only be recognized for their mathematical esthetics. Herman Weyl's 1929 prediction of hypothetical massless fermions is a prime example because their existence was never confirmed in particle-physics experiments but was instead observed in solid-state quantum materials (*1*).

Observing "pseudo-relativistic electrons" in materials is not completely surprising, given the formal equivalence between the Dirac or Weyl equations describing relativistic elementary particles and the effective Schrödinger equation describing electronic excitations in semimetals (*1*). Beyond this formal analogy, the pseudo-relativistic band structure of Weyl semimetals also hosts a robust mathematical property, a so-called topological defect that cannot be removed under small deformations of the crystal (*1*). To appreciate this notion, one should first realize that a fictitious "magnetic" field (also called Berry curvature) can be associated with the energy bands of crystalline struc-

Tunable Weyl nodes for ultracold atoms

The engineering of Weyl-type band structures in optical lattices relies on correlating the spin and momentum of the atoms along all three spatial directions. By realizing such a spin-orbit coupling (SOC), Wang *et al*. formed and tuned a Weyl-type band structure for ultracold rubidium atoms.



Tuning spin-orbit coupling
Cold atoms in two internal states (spin-up and spin-down) move on a three-dimensional (3D) optical lattice in the presence of laser-induced SOC. Tomography was used to extract the spin texture in momentum space.

Varying Weyl points
Tuning 3D SOC modifies the band structure and creates configurations with different numbers of Weyl nodes. Nodes always come in pairs with opposite topological charges (+ and –).

GRAPHIC: C. BICEKL/SCIENCE

Science

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