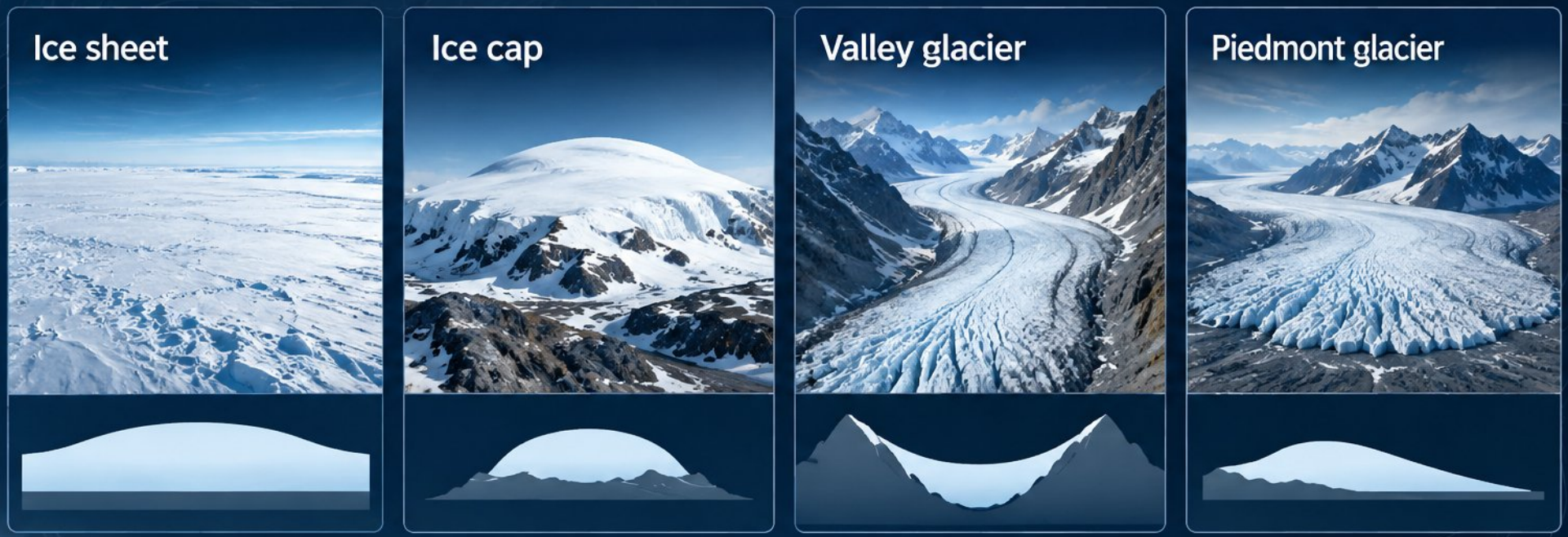
Glaciers: How Ice Shapes Landscapes



- **Goals:** how ice forms, flows, erodes, and deposits to shape landforms
- **Vital resource:** freshwater for nearly 10% of the world's population
- **Sea level:** glaciers drive 25–30% of current global rise
- **Scale:** 215,000+ glaciers cover ~700,000 km^2, holding 158,000 km^3 of ice
- **Guiding question:** how can a slowly moving solid reshape a continent?

Glacier Types and the Global Ice Inventory

- Glacier: perennial ice that flows under its own weight, not seasonal snow
- Forms range from ice sheets and ice caps to valley and piedmont glaciers
- Peripheral glaciers around ice sheets hold about 30% of global glacier area
- The Randolph Glacier Inventory outlines over 215,000 glaciers
- Total volume near 149,000 km³, about 308 ± 60 mm of sea level



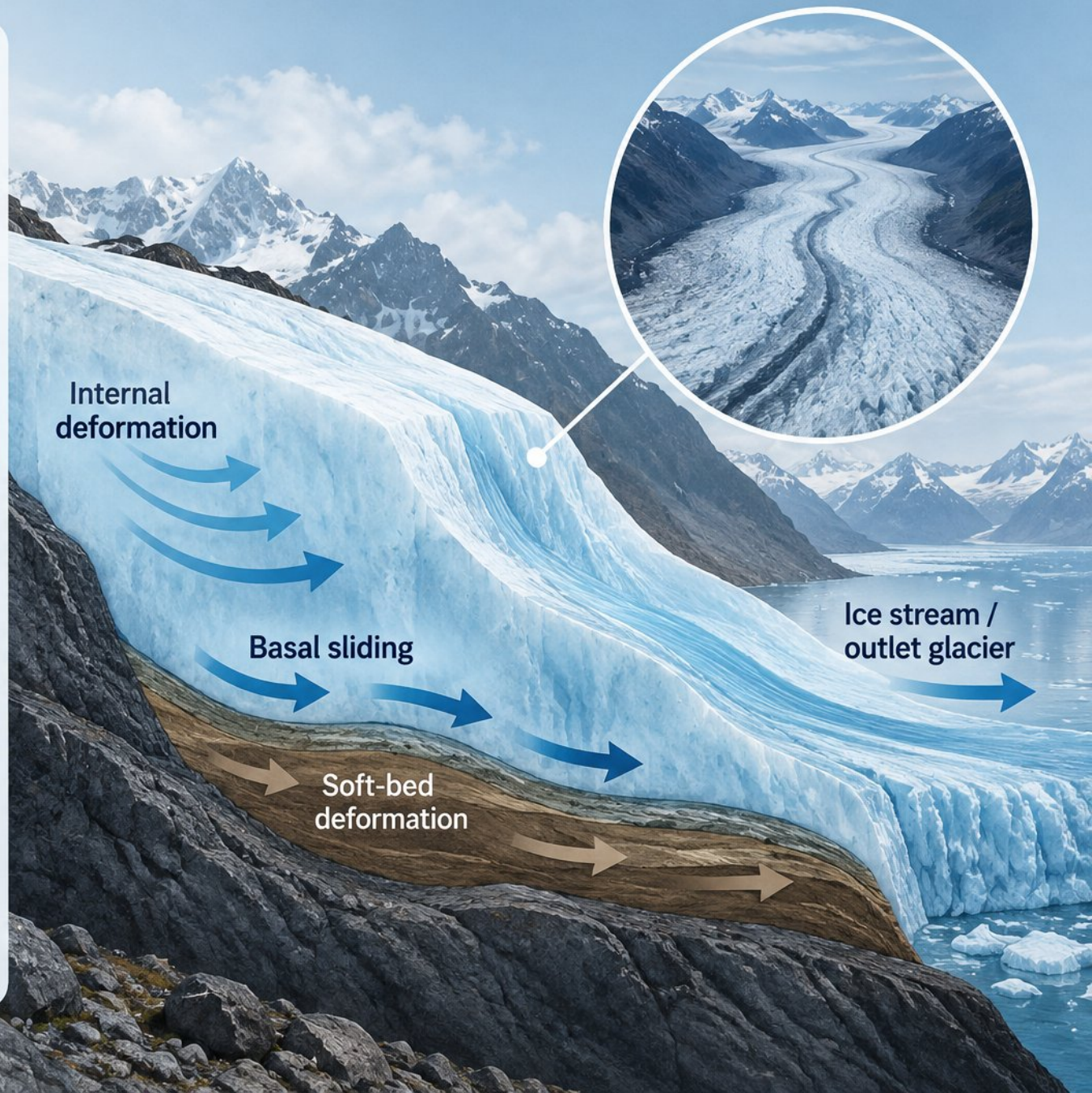
From Snow to Ice: Formation and Mass Balance

- Snow accumulates, compacts into firn, then dense glacial ice
- Accumulation zone versus ablation zone, divided by the equilibrium line altitude
- Positive, negative, or balanced mass balance; size responds over decades to centuries
- Warming pushes the ELA upward, forcing termini into retreat
- Toolkit: snow pits, ablation stakes, weather stations, DEM differencing, altimetry, gravimetry, GNSS-IR



How Ice Moves: Deformation, Sliding, and Surges

- Three flow mechanisms: internal deformation, basal sliding, and soft-bed deformation
- Driving stress rises with ice thickness and surface slope
- Basal motion depends on water pressure and bed conditions, not simple friction
- Ice streams and outlet glaciers reach kilometers per year
- Surge-type glaciers speed up by orders of magnitude, then return to quiescence
- Flow style sets the pattern of erosion and the pace of landscape change



Glacial Erosion and Sediment Transport

- Abrasion: debris-charged basal ice grinds bedrock smooth
- Plucking/quarying: ice lifts and removes bedrock blocks
- Quarrying can be ~5x more effective than abrasion locally
- Erosion depends on sliding velocity and basal shear stress ("basal power")
- Rates: ~0.01–1 mm/yr; soft karst limestone erodes far slower
- Transport paths: supraglacial, englacial, subglacial—feeding rock flour downstream



Erosional Landforms: Valleys, Cirques, and Fjords

- Glacial troughs: parabolic/U-shaped, flat floors, steep walls — fjords where over-deepened below sea level
- Truncated spurs and hanging valleys; Bridalveil Fall, Yosemite, marks a tributary junction
- Alpine trio: cirques carve bowls, arêtes form knife-edge ridges, horns are pyramidal peaks (Matterhorn)
- Small-scale evidence: roches moutonnées, whalebacks, striations revealing flow direction
- Interpret landscapes by cross-profile shape, valley-floor gradient, and tributary geometry







Depositional Landforms: Moraines, Till, and Outwash





- **Till** is **unsorted**; **stratified drift** is sorted by meltwater — texture reveals ice behavior
- **Terminal, lateral, medial, recessional moraines** mark former ice margins
- **Drumlins, eskers, kames, outwash plains**: eskers are casts of subglacial meltwater channels
- **Subglacial bedforms** form a continuum shaped by ice, meltwater, and till deformation
- **Date moraines and outwash** with cosmogenic exposure and optically stimulated luminescence



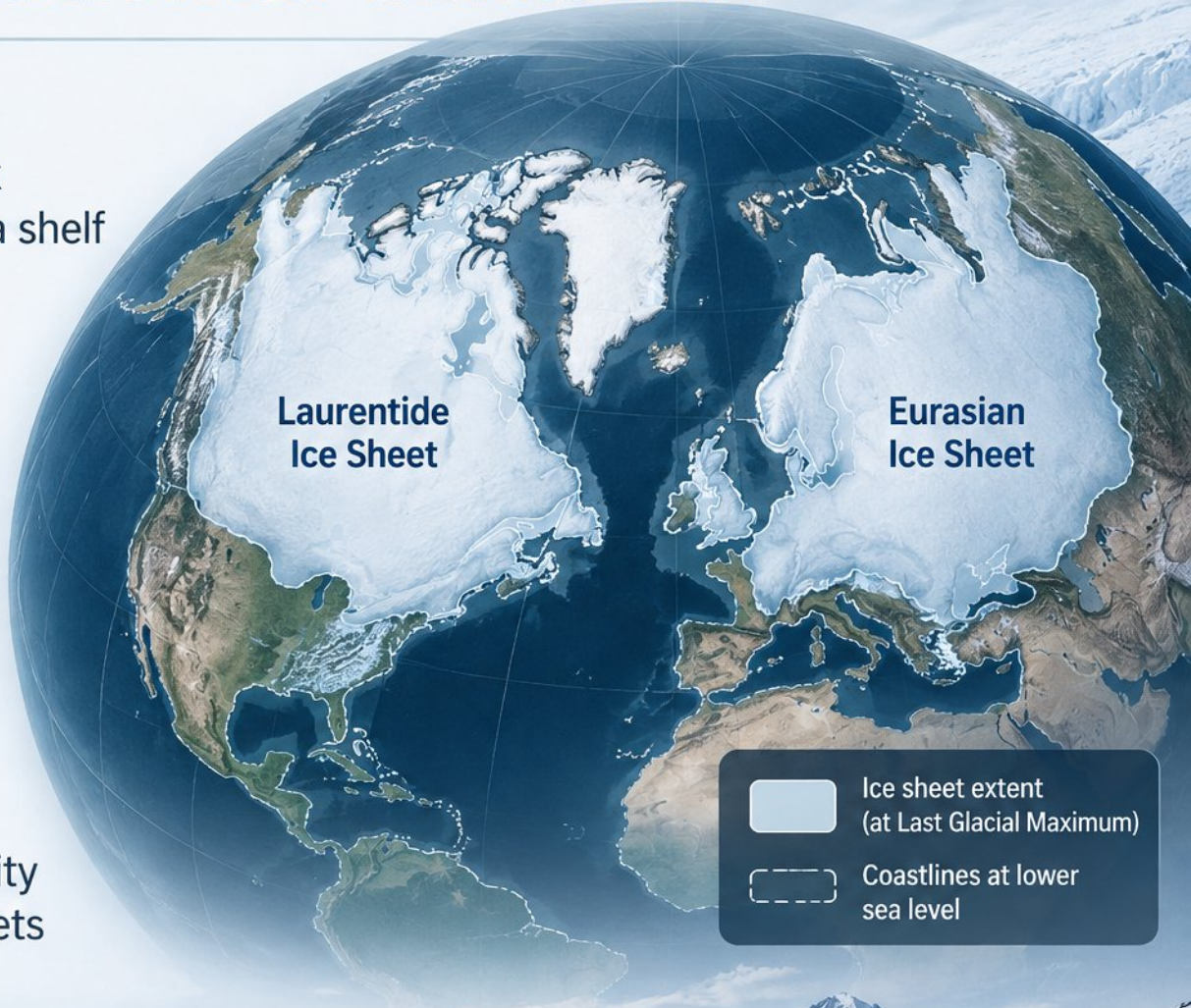
Glacial Lakes, Outburst Floods, and Mountain Hazards



- Ice-dammed, moraine-dammed, and supraglacial lakes store meltwater
- GLOFs trigger from lake growth, dam overtopping, hydrofracture, or landslides
- July 2025 Gyirong and Purepu events caused deaths and transboundary damage
- August 2025 Talidas GLOF followed meltwater-driven expansion and moraine overtopping
- 388+ GLOF events documented in Himalaya–Karakoram
- High-frequency optical and radar imagery drive early warning

Ice Ages and Continental Glaciation

- Pleistocene ice sheets: Laurentide over North America; Eurasian complex over Britain, Scandinavia, Barents–Kara shelf
- Last Glacial Maximum roughly 27,000–21,000 years ago; local maxima varied by region
- At LGM, ice covered ~25% of global land; sea level was ~125–130 m lower
- Glacio-isostatic adjustment and postglacial rebound continue today in formerly glaciated regions
- Past ice-sheet change reveals sensitivity and response times of today's ice sheets



Last Glacial Maximum
Roughly 27,000–21,000 years ago

Glaciers Today: Global Change, Water, and Sea Level

- Accelerating loss: from under 100 Gt/yr (1976–1995) to ~390 Gt/yr (2016–2025)
- 2025: 408 ± 132 Gt lost — 1.1 ± 0.4 mm of sea-level rise, sixth most negative year
- Since 1975: 9,583 ± 1,211 Gt lost, 26.4 ± 3.3 mm sea-level rise; 79% since 2000
- Projections to 2100: 26 ± 10% volume loss (low emissions), 47 ± 17% (high emissions)
- Water stakes highest in High Mountain Asia, the Andes, and the Alps — monitoring matters

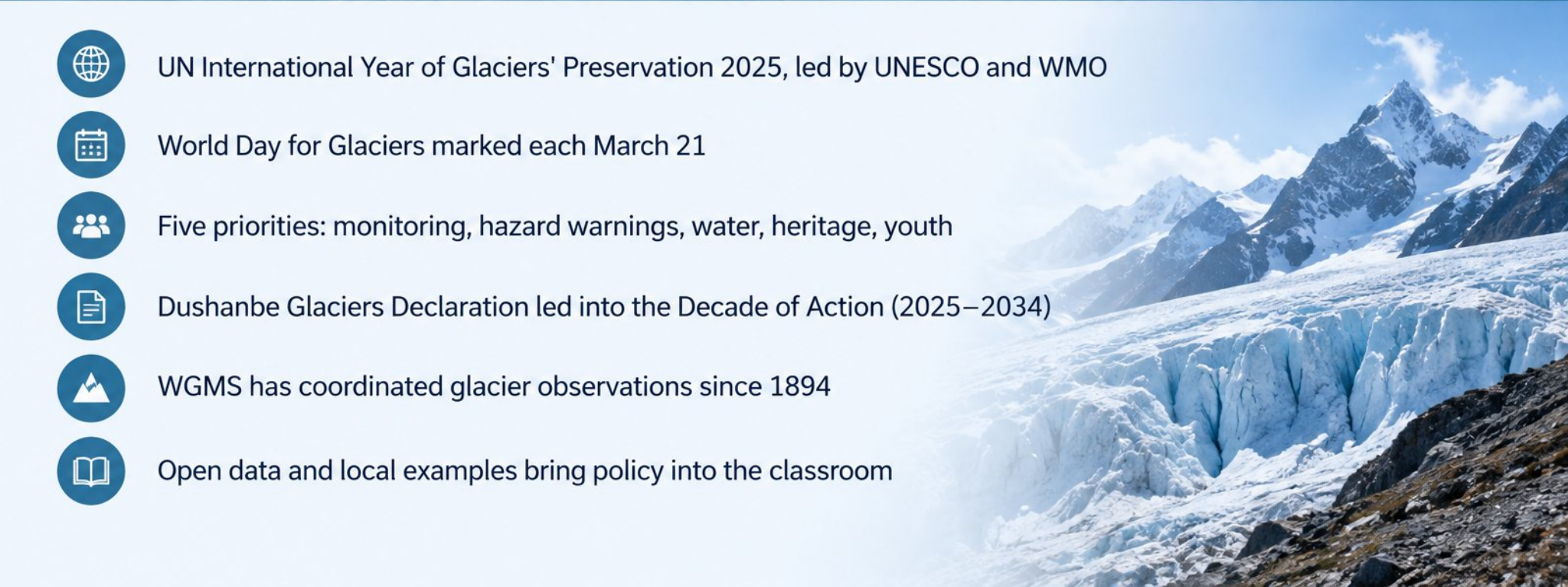


Monitoring Policy: From the International Year of Glaciers to a Decade of Action

PEOPLE | DATA | ACTION FOR A HEALTHY CRYOSPHERE



- UN International Year of Glaciers' Preservation 2025, led by UNESCO and WMO
- World Day for Glaciers marked each March 21
- Five priorities: monitoring, hazard warnings, water, heritage, youth
- Dushanbe Glaciers Declaration led into the Decade of Action (2025–2034)
- WGMS has coordinated glacier observations since 1894
- Open data and local examples bring policy into the classroom



Teaching Ice Flow and Erosion with Simple Models

- Flubber in a half-pipe valley shows internal deformation and slope effects
- Layered goo with gravel models plucking, transport, and deposition
- Freeze-and-expand jar demonstrates frost wedging at a glacier headwall
- OGGM-Edu Glacier Simulator links hands-on models to numerical flow models
- Design experiments: hypothesis, measurement, and comparison with real glaciers



Reading Your Local Landscape: Field and Data Activities

- Field walks: trace striations, erratics, moraines, kames, kettle lakes
- Free satellite imagery plus WGMS and Copernicus mass-balance datasets
- Compare repeat photos, U- vs V-shaped valleys, LGM ice maps
- Assess with landform interpretation and short data prompts
- Correct myths: glaciers don’t sled; not all valleys are glacial



Synthesis and Action: Why Ice-Shaped Landscapes Matter

- Snow → ice → flow → erosion → deposition → landforms: one connected chain
- Past ice ages, present loss, and future projections form one continuous story
- Students seek evidence; citizens stay informed; teachers interpret local landscapes
- Monitor a glacier-fed stream, share repeat imagery, use open data
- What will these landscapes look like in 2100?



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