

# Planetary Energy Imbalance, ENSO Variability and Cryospheric Instability: A Multi-Scale Analysis of Himalayan Climate Risk and the 2026 Nepal Flood

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## Research Article

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# Abstract

## Background

Earth's climate system is accumulating energy, while high-mountain cryospheric systems are undergoing sustained change. The physical significance of this energy accumulation is most clearly expressed through Earth's energy imbalance (EEI), ocean heat uptake, glacier mass loss and changes in snow and permafrost conditions. High-mountain disasters, however, are rarely produced by a single forcing. They emerge from interactions among long-term warming, short-term climate variability, hydrology, geology and human exposure.

## Objective

This study develops a multi-scale analytical framework linking planetary energy imbalance, ENSO variability, Himalayan cryospheric change and compound mountain hazards, using the 26 August 2026 Rasuwa/Langtang Lirung disaster as a contemporary case study.

## Methods

The study uses secondary observational and assessment evidence from peer-reviewed Earth-system literature and authoritative scientific and governmental sources. EEI evidence, glacier and cryosphere observations, ENSO information, freezing-level changes, and documented characteristics of the 2026 event are compared within a process-based framework. The analysis deliberately distinguishes long-term climatic preconditioning from immediate geological and hydrometeorological triggers.

## Results

Published observations show a substantial increase in EEI since the beginning of the twenty-first century. Satellite-based analysis reported an increase from about  $0.5 \pm 0.2 \text{ W m}^{-2}$  in the first decade of the century to about  $1.0 \pm 0.2 \text{ W m}^{-2}$  in the subsequent decade. The greater-Himalaya literature documents sustained glacier mass loss, while the 2026 event assessment identifies warming, permafrost degradation, changing precipitation phase, glacier recession and possible legacy effects of the 2015 earthquake as interacting contributors to slope instability. The evidence does not support treating EEI or ENSO as a single direct cause of the disaster.

## Conclusions

“Planetary Fever” is used here as a conceptual descriptor—not a new physical variable—for persistent positive energy imbalance in the Earth system. The case study supports a multi-hazard interpretation in

which long-term warming changes the boundary conditions of mountain systems, while geological structure and short-term meteorological variability determine how and when failure occurs. Integrated cryosphere, slope, hydrological and atmospheric monitoring is therefore more informative than attribution to a single forcing.

## 1. Introduction

Earth's energy budget provides a physical basis for understanding long-term climate change. A positive Earth's energy imbalance (EEI) means that, on average, the Earth system absorbs more energy than it returns to space. The resulting excess energy is distributed primarily into the ocean, with smaller fractions affecting the land, atmosphere and cryosphere. Recent observational work using satellite and in situ measurements indicates that EEI has increased substantially during the modern observational period [1, 2]. The World Meteorological Organization (WMO) has incorporated EEI among its key climate indicators and reports that 2015–2025 were the eleven warmest years in the instrumental record [3].

The climatic significance of EEI is not restricted to mean surface temperature. Energy accumulation changes the physical boundary conditions of the entire Earth system. Ocean heat uptake, sea-level rise, glacier mass loss, snow-cover changes, permafrost degradation and atmospheric circulation are interconnected manifestations of the same energy budget. In high mountains, these changes can affect the mechanical and hydrological state of slopes and glaciers. A persistent climatic forcing does not, however, mechanically trigger an individual landslide or flood. Local failure depends on geological structure, slope geometry, water pressure, ice bonding, precipitation and other immediate conditions.

The present study focuses on the Himalaya because it is a particularly sensitive environment in which cryospheric change intersects with steep terrain, active tectonics, monsoon precipitation and dense downstream infrastructure. Long-term observations show substantial glacier mass loss across High Mountain Asia, including the Langtang region [4]. Recent work has also demonstrated that glacial-lake development and associated mass loss can introduce additional hydrological and hazard complexity [5].

The 26 August 2026 Rasuwa disaster provides an unusually important contemporary case study. The World Weather Attribution (WWA) assessment describes a large rock-wall and glacier-ice collapse from the Langtang Lirung area, followed by rapid transformation into a debris flood and water-dominated flash flood. The assessment identifies geological predisposition as fundamental while also finding that warming, permafrost degradation, glacier recession and changing precipitation phase may have reduced slope stability [6].

This paper therefore does not ask whether global warming 'caused' the 2026 disaster in isolation. Instead, it asks how planetary-scale energy accumulation, regional climate variability and cryospheric transformation can alter the background state in which geological and hydrometeorological processes produce compound hazards.

## 2. Research Questions and Objectives

The study addresses five questions:

- How has Earth's energy imbalance changed during the modern observational period, and what physical processes are associated with that change?
- How should ENSO variability be represented as a short-term modifier of a longer-term warming background rather than as an independent source of planetary heat?
- What evidence exists for sustained cryospheric change in the Himalaya, particularly glacier mass loss and upward displacement of the freezing level?
- Which interacting physical processes are documented or proposed for the 26 August 2026 Langtang Lirung/Rasuwa disaster?
- How can these processes be integrated into a multi-hazard observing and early-warning framework?

The objective is therefore not to establish a new attribution estimate for the 2026 disaster, but to construct an evidence-based multi-scale framework that connects measurable Earth-system changes to cryospheric and mountain-risk processes.

## 3. Materials and Methods

### 3.1 Study design

This work is a secondary-data analytical case study. It does not present a newly collected field dataset or claim an original formal event-attribution calculation. Instead, it synthesizes quantitative results already reported in peer-reviewed studies and authoritative assessments and places them within a common physical framework. This distinction is important because the 2026 disaster is recent and the complete observational record is still being assembled.

### 3.2 Evidence domains

| Domain                      | Evidence used                                                    | Analytical purpose                                                 |
|-----------------------------|------------------------------------------------------------------|--------------------------------------------------------------------|
| Earth energy imbalance      | Satellite and Earth-system energy-budget studies; WMO assessment | Establish planetary-scale background forcing and its uncertainty   |
| ENSO                        | NOAA Climate Prediction Center diagnostics                       | Characterize interannual ocean–atmosphere variability              |
| Glacier change              | Peer-reviewed High Mountain Asia/Langtang studies                | Evaluate long-term cryospheric preconditioning                     |
| Freezing level / permafrost | 2026 WWA assessment and cited observations                       | Evaluate thermal controls on ice and rock stability                |
| 2026 disaster               | WWA scientific assessment and Nepal government report            | Reconstruct the documented event sequence and contributing factors |
| Risk management             | Scientific monitoring and hazard literature                      | Translate physical findings into an observing framework            |

### 3.3 Earth's energy imbalance

EEl is treated as the net top-of-atmosphere energy flux into the Earth system. Published CERES-based analyses are used as the primary quantitative evidence. Loeb et al. reported an increase from approximately  $0.5 \pm 0.2 \text{ W m}^{-2}$  during the first decade of the twenty-first century to approximately  $1.0 \pm 0.2 \text{ W m}^{-2}$  during the following decade [1]. The analysis also showed that changes in absorbed shortwave radiation and outgoing longwave radiation contributed to the observed net imbalance. These results are used descriptively rather than re-estimated in the present paper.

## 3.4 ENSO representation

ENSO is treated as an internal mode of ocean–atmosphere variability that redistributes heat and alters atmospheric circulation on interannual timescales. NOAA's May 2026 diagnostic discussion placed the system in an El Niño Watch and reported an 82% chance of El Niño emergence during May–July 2026, while emphasizing uncertainty in event strength [7]. This information is used only to establish the contemporaneous ENSO state and not to infer a causal contribution to the Langtang failure without regional observations.

## 3.5 Cryospheric indicators

The analysis uses published glacier mass-balance results and the documented direction of change in the Himalayan cryosphere. A multi-temporal satellite study reported sustained mass loss in the Langtang sub-region, including approximately  $-0.58 \pm 0.11 \text{ m}$  water equivalent per year during 2015–2019, compared with lower losses during earlier periods [4]. A separate Nature Geoscience study found substantial expansion of proglacial lakes across the greater Himalaya between 2000 and 2020 and identified additional mass loss not captured by conventional geodetic estimates [5].

## 3.6 2026 event reconstruction

The 26 August 2026 event is reconstructed from the WWA scientific assessment and the Government of Nepal Ministry of Home Affairs disaster notice [6, 8]. The WWA assessment describes a large rock-wall collapse with overlying glacier ice, a fall of approximately 1,400 m, rapid transformation into a debris flood, and subsequent water-dominated flooding. It identifies geological structure as fundamental while discussing warming, permafrost degradation, glacier recession, precipitation-phase change and possible legacy effects of the 2015 earthquake as contributing factors [6].

## 3.7 Analytical framework

The physical framework is organized as a sequence of scales: planetary energy imbalance → background warming → cryospheric transformation → hydrological and thermal stress, with ENSO and seasonal variability acting as modifiers and geological structure providing a local susceptibility field. The final hazard state emerges from the interaction of these processes rather than from a single forcing.

## 4. Results

### 4.1 Earth-system energy accumulation

The principal planetary-scale result is that EEI has increased during the modern observational period. CERES-based analysis reported a near doubling of the decadal mean imbalance from  $0.5 \pm 0.2 \text{ W m}^{-2}$  in the first decade of the century to  $1.0 \pm 0.2 \text{ W m}^{-2}$  in the subsequent decade [1]. The same study attributed the increase to a combination of increased absorbed solar radiation and partially compensating changes in outgoing longwave radiation. WMO's 2026 State of the Global Climate report independently identifies the Earth's energy imbalance as being at its highest level in its 65-year observational record [3].

These observations support the use of 'Planetary Fever' as a communication term for persistent positive energy imbalance, provided that the term is not treated as a new physical observable. The scientifically defined quantity remains EEI.

### 4.2 ENSO as a short-term climate modifier

The 2026 ENSO state provides an example of the distinction between background forcing and internal variability. NOAA reported that El Niño was likely to emerge in May–July 2026 and persist into the Northern Hemisphere winter of 2026–27, while also noting uncertainty in the event's eventual strength [7]. In the present framework, ENSO therefore represents a potential modulator of regional circulation, precipitation and temperature superimposed on a longer-term warming background.

No new statistical attribution between ENSO indices and the Langtang event is calculated here. Consequently, the manuscript does not claim that ENSO directly triggered the 26 August failure.

### 4.3 Himalayan cryospheric change

Published satellite evidence demonstrates persistent glacier mass loss in the Himalaya and specifically in the Langtang-related region. In the study by Brun et al., the Langtang sub-region showed a mean mass-loss rate of approximately  $-0.58 \pm 0.11$  m water equivalent per year for 2015–2019, compared with approximately  $-0.50 \pm 0.11$  m water equivalent per year for the broader recent period 2004–2019 [4]. These values demonstrate that the cryosphere is undergoing sustained transformation.

Additional evidence from Zhang et al. shows that proglacial lakes in the greater Himalaya increased substantially in number, area and volume between 2000 and 2020, with previously unaccounted-for subaqueous glacier mass loss contributing to uncertainty in regional mass budgets [5]. Together, these studies indicate that cryospheric change is not simply a visual consequence of warming; it changes the hydrological and mechanical environment in which mountain hazards develop.

## **4.4 Thermal and mechanical preconditioning**

The 2026 WWA assessment reports an upward shift of the  $0^{\circ}\text{C}$  level of approximately 100 m per decade in recent decades during the monsoon and post-monsoon seasons, along with evidence of warming and permafrost degradation at high elevations [6]. In ice-filled fractures, warming and thaw can reduce the mechanical bonding provided by ice. Meltwater can additionally increase hydraulic pressure along discontinuities. These processes provide physically plausible mechanisms by which long-term warming can alter slope stability, but they do not determine the exact timing of failure.

## **4.5 The 26 August 2026 Langtang Lirung/Rasuwa event**

The available scientific reconstruction describes a large rock-wall collapse from the Langtang Lirung area at approximately 5,150 m elevation, involving overlying glacier ice. The material fell roughly 1,400 m and transformed into a rapidly moving debris flood and then a water-dominated flash flood. The WWA assessment reports that the downstream flow reached the Rasuwagadhi border 22 km away within approximately seven minutes [6].

The event therefore has at least four analytically distinct components: (i) geological susceptibility of the source slope; (ii) long-term cryospheric and thermal preconditioning; (iii) short-term meteorological and hydrological conditions; and (iv) downstream exposure and infrastructure vulnerability. The Government of Nepal independently confirmed a major Bhote Koshi flood on 26 August 2026 and described severe impacts across Rasuwa, Nuwakot, Dhading and Gorkha districts [8].

| Process scale        | Evidence                                                | Interpretation                                        | Causal confidence                      |
|----------------------|---------------------------------------------------------|-------------------------------------------------------|----------------------------------------|
| Planetary            | Positive EEI and continued global warming               | Changes the long-term thermal boundary condition      | High for warming; not an event trigger |
| Regional             | Himalayan glacier mass loss; rising freezing level      | Cryospheric and thermal preconditioning               | Moderate–high                          |
| Seasonal/interannual | 2026 ENSO state and anomalous regional conditions       | Potential modulation of circulation and precipitation | Context-dependent                      |
| Local geological     | Fractured mountain terrain; legacy seismic effects      | Controls where failure can occur                      | High for geological susceptibility     |
| Immediate event      | Rock–ice collapse and rapid debris/flood transformation | Initiates the observed cascade                        | High                                   |
| Societal             | Settlements, hydropower and transport in valleys        | Controls downstream consequences                      | High                                   |

## 4.6 Integrated interpretation

The results support a telescoping hazard model. Planetary energy accumulation operates over decades; regional cryospheric transformation develops over years to decades; seasonal and interannual variability modifies thermal and hydrological conditions over months; geological instability determines local susceptibility; and the final failure can occur within minutes. The 2026 event is therefore consistent with a compound-hazard model in which multiple processes operate on different timescales.

## 5. Discussion

### 5.1 From planetary energy imbalance to mountain risk

The central physical insight is that small persistent imbalances in the global energy budget can accumulate to large changes in slowly responding components of the Earth system. The ocean stores most of the excess energy, but the cryosphere provides a particularly visible and mechanically important response in mountain regions. Glacier thinning, snowline changes and permafrost degradation can modify water availability, surface loading, ice bonding and slope hydrology.

The connection is therefore indirect rather than deterministic. A positive EEI does not imply that a specific mountain must fail. Instead, it changes the statistical and physical environment in which failure thresholds are approached.

### 5.2 Clarifying the role of 'cosmic' or solar forcing

The original manuscript used the expression 'cosmic warming'. The revised analysis does not use this phrase as a claim that solar or cosmic forcing is the primary explanation for contemporary global warming. The evidence cited here instead supports anthropogenic radiative forcing as the fundamental driver of the long-term warming trend, while solar variability, clouds, aerosols and internal variability can affect components of the Earth radiation budget [1, 3]. Solar observations remain scientifically valuable for understanding the Sun–Earth system, but they should not be presented as an alternative attribution without quantitative evidence.

## **5.3 ENSO and the danger of single-event attribution**

ENSO can alter ocean–atmosphere circulation and regional climate, but its presence does not establish causation for a particular Himalayan failure. The appropriate interpretation is that ENSO may change the timing or magnitude of regional temperature and precipitation anomalies against a background state that has itself been altered by long-term warming.

## **5.4 Glacier retreat, permafrost and debuttreassing**

Glacier retreat can change the mechanical boundary conditions of adjacent terrain. Loss of ice may remove buttressing, while meltwater can alter pore pressure and drainage pathways. Permafrost degradation provides a separate mechanism through which warming can weaken ice-filled rock fractures. These mechanisms are mutually reinforcing in some environments but should not be assumed to operate with the same magnitude everywhere.

## **5.5 The 2015 earthquake as a possible legacy factor**

The 2026 WWA assessment notes that the 2015 magnitude-7.8 earthquake triggered extensive landsliding and may have contributed to long-term slope weakening. However, the assessment also states that the specific contribution of the earlier earthquake to the 2026 failure cannot yet be quantified [6]. The present study therefore treats the earthquake as a plausible preconditioning factor rather than an established quantitative cause.

## **5.6 Implications for climate-risk science**

The case illustrates why climate-risk studies in high mountains should integrate atmospheric, cryospheric, geological and hydrological observations. A rainfall-only warning system can miss rapid cascades initiated by rock–ice collapse. Conversely, a purely cryospheric monitoring system may miss extreme precipitation or river routing. The relevant unit of analysis is the coupled hazard cascade.

## **5.7 Proposed Himalayan observatory framework**

A practical observing architecture should integrate satellite observations, automatic weather stations, glacier mass-balance measurements, snow depth, permafrost boreholes, slope deformation, river discharge, pore-pressure measurements and seismic monitoring. India's long-term solar observations, including the Kodaikanal Solar Observatory archive, could contribute to the Sun–Earth component of

such a network, but should be integrated with Earth-system observations rather than treated as a stand-alone climate attribution dataset.

## **6. Implications for Early Warning and Infrastructure**

### **6.1 Cryosphere–geology early warning**

Early warning should move beyond rainfall and river-level monitoring toward combined detection of glacier movement, rock deformation, permafrost temperature, snow and ice conditions, pore pressure and downstream discharge. The aim is not to predict every failure, but to detect combinations of conditions associated with elevated susceptibility.

### **6.2 Climate-sensitive hydropower planning**

Himalayan hydropower corridors should be evaluated against changing glacier geometry, permafrost conditions, precipitation phase, debris-flow pathways and slope deformation. Risk assessments should account for the lifetime of infrastructure rather than relying only on historical climate statistics.

### **6.3 Transboundary data sharing**

The Bhote Koshi and connected Himalayan river systems cross political boundaries. Real-time exchange of observations on rainfall, snow, glacier movement, river discharge and slope deformation could improve situational awareness. The physical continuity of the mountain and river systems makes scientific information sharing a necessary component of hazard management.

### **6.4 Climate vulnerability and downstream exposure**

The consequences of high-altitude failures are strongly controlled by exposure. Roads, bridges, hydropower installations, markets and settlements located along confined valleys can experience large impacts from very short-lived upstream events. Climate adaptation therefore requires both physical monitoring and spatial planning.

## **7. Limitations**

- The study is based on secondary evidence and does not introduce a newly collected field dataset.
- No formal probabilistic event-attribution calculation for the 26 August 2026 disaster is performed.
- The 2026 event is recent; scientific reconstruction and casualty/damage estimates remain subject to revision as additional observations become available.
- The available evidence does not justify assigning a numerical causal fraction of the disaster to EEI, ENSO, glacier retreat, permafrost degradation or the 2015 earthquake.
- The use of 'Planetary Fever' is conceptual and communicative; EEI is the established physical metric.

- Relationships among planetary-scale, regional and local processes are presented as a process-based framework rather than as a validated predictive model.

## 8. Conclusions

This study reframes the original 'Planetary Fever' concept as a physically grounded description of persistent positive Earth-system energy imbalance. The established scientific quantity is EEI, and recent observations show that it has increased substantially during the modern observational period [1, 3].

The Himalayan cryosphere provides a sensitive interface between this planetary-scale energy accumulation and local mountain processes. Published observations demonstrate sustained glacier mass loss in the Langtang region and broader Himalayan changes in glacier and proglacial-lake conditions [4, 5]. The 2026 Langtang Lirung/Rasuwa disaster demonstrates how long-term cryospheric and thermal changes can coexist with geological susceptibility and short-term hydrometeorological stress in producing a rapidly cascading hazard [6, 8].

The evidence does not support attributing the event to a single factor. Instead, the scientifically defensible interpretation is a multi-timescale cascade: planetary energy imbalance changes the background climate state; warming transforms snow, glacier and permafrost conditions; seasonal and interannual variability modifies hydrological stress; geological structure controls local susceptibility; and a rapid rock–ice collapse initiates the immediate disaster.

Future Himalayan risk reduction should therefore integrate Earth-system energy monitoring, climate observations, cryosphere measurements, geological surveillance, hydrological sensing and transboundary early-warning systems. Such integration provides a more testable and operational framework than single-cause explanations of complex mountain disasters.

## Declarations

### Preprint Submission Note

This manuscript has been substantially reframed from the previously submitted general review into a Research Article-style secondary-data analytical case study. The revised manuscript does not claim original field measurements or a new formal attribution model. Its results are explicitly limited to the evidence that can be supported by published observations and authoritative assessments.

### Ethics approval and consent to participate

Not applicable. The study uses published and publicly available environmental, climate and disaster information and involves no human participants or identifiable personal data.

### Consent for publication

Not applicable.

### **Competing interests**

The author declares no competing interests.

## **Funding**

No specific external funding was received for this study.

## **Author contributions**

C.S.A.R. conceived the interdisciplinary framework, reviewed the climate and cryosphere evidence, developed the physical interpretation, prepared the manuscript and approved the final version.

## **Data availability**

No new primary dataset was generated. The analysis is based on published and publicly available sources identified in the reference list.

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# Figures

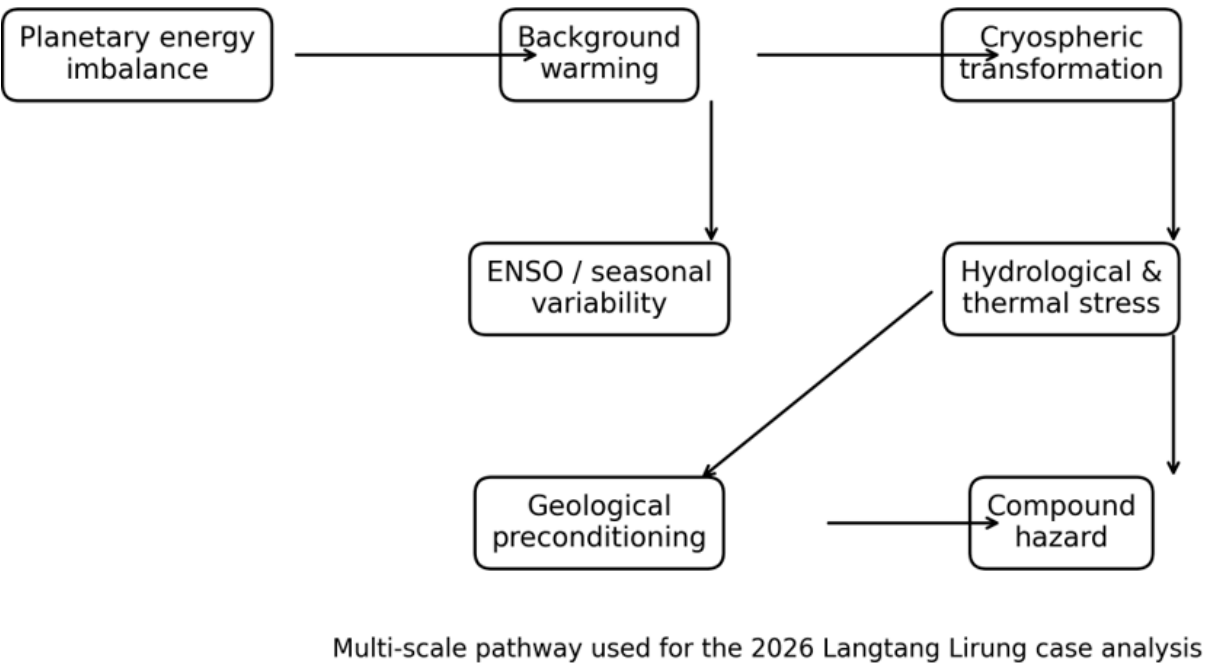


**Figure 1**

*Multi-scale physical framework used in the present case analysis. The arrows indicate conceptual process relationships and do not imply a quantified causal coefficient.*