Climate Drivers of Equilibrium Line Altitude Changes at Four Low-Latitude Andean Glaciers:
Different Drivers, But Likely Continued Retreat In a Warming World

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Douglas MacAyeal
South America Is Ideal For Tropical Glacier Study

1. Tropical Glaciers
2. ELA Modeling
3. ELA Drivers
4. Implications

(Randolph Glacier Inventory)

2,893 glaciers (~98%)
2,338 km² (>99%)
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Adapted, Gardner et al., 2013

(Randolph Glacier Inventory)

2,893 glaciers (~98%)
2,338 km (>99%)

Antarctic & Sub-Arctic
Southern Andes
Low Latitudes
Himalayas
North Asia
Russian Arctic
Scandinavia
Svalbard
Iceland
Greenland
Arctic Canada (South)
Arctic Canada (North)
Western Canada/US
Alaska

Mass loss rate (kg m\(^{-2}\) y\(^{-1}\))
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(adapted, Gardner et al., 2013)
What are the dominant climate forcings that dictate tropical glacier variability in the recent past?
Equilibrium Line Altitude As a Metric of Glacier Change

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(modified, Kaser, 2001)
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Equilibrium Line Altitude (ELA)

Accumulation Zone

Ablation Zone

Bedrock

Direction of flow

(gain)

(loss)

Equilibrium line

Effective balance

0

Δz [m]

Δb [kg m\(^{-2}\) a\(^{-1}\)]

(modified, Kaser, 2001)
Quantify Glacier Change Using an Energy Balance Model

Radiative Fluxes
- $S_{\text{down}}$
- $S_{\text{up}}$
- $L_{\text{down}}$
- $L_{\text{up}}$

Turbulent Fluxes
- $Q_S$
- $Q_L$
- $Q_R$

Other Fluxes

Ice Surface

$Q_G$
Quantify Glacier Change Using an Energy Balance Model

**Inputs**

**Climate Signal**

Radiative Fluxes: $S_{\text{down}}$, $S_{\text{up}}$, $L_{\text{down}}$, $L_{\text{up}}$

Turbulent Fluxes: $Q_S$, $Q_L$

Other Fluxes: $Q_R$

Ice Surface: $Q_G$
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**Inputs**

- Climate Signal

**Model**

- Energy Balance Model

**Radiative Fluxes**

- $S_{\text{down}}$
- $S_{\text{up}}$

**Turbulent Fluxes**

- $Q_{S}$
- $Q_{L}$
- $Q_{R}$

**Other Fluxes**

- Turbulent Fluxes
- Radiative Fluxes

**Ice Surface**

- $Q_{G}$
Quantify Glacier Change Using an Energy Balance Model

**Inputs**
- Climate Signal

**Model**
- Energy Balance Model

**Outputs**
- Vertical Balance Profile

**Radiative Fluxes**
- $S_{\text{down}}$
- $S_{\text{up}}$

**Turbulent Fluxes**
- $Q_S$
- $Q_L$
- $Q_R$

**Other Fluxes**
- Turbulent Fluxes
- Other Fluxes

**Ice Surface**
- Summed Over Thermal Year
- Equilibrium Line Altitude (ELA)
Long-term ELA Tracks Climate Setting of Glacier

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Mean Climatological ELA
Wet Tropical Glacier ELAs Track Freezing Level Heights

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- ELA: Freezing Level Height
- Precipitation Rate

Map showing locations of wet tropical glaciers with circles indicating different areas.

Graph showing time series data for elevation anomalies (m) with different scales for precipitation rate (m y⁻¹). Coefficients of correlation (r) indicated for different intervals.
Dry Tropical Glacier ELAs Mainly Track Precipitation
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Graph showing trends in NINO 3.4 (°C) and its correlation with ELA at different locations:
- Salama: r = 0.55, p < 0.01
- Huascaran: r = 0.51, p < 0.01
- Illimani: r = 0.64, p < 0.01
- Quecay: r = 0.44, p < 0.05
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Tropical Glaciers Respond to Regional Climate Trends
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Tropical Glaciers Respond to Regional Climate Trends

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ELAs of sublimation-dominated glaciers strongly respond to precipitation rate changes but the freezing level height dictates the lowest ELAs.
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(NOAA)
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Tropical Glaciers Repsond to Regional Climate Trends

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