

**UNIVERSITY
AT ALBANY**
State University of New York

Climate Change in the tropical Andes and its impacts on glaciers: observations and projections

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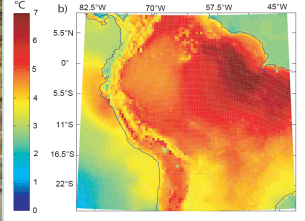
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Part I: Current observations

Observations of glacier retreat

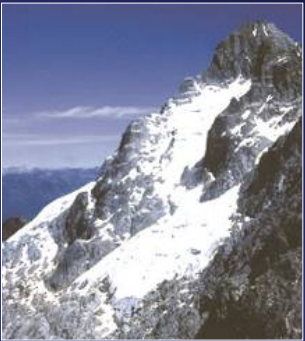
Glacier Espejo, Pico Bolivar (5002 m)
Venezuela

< 2 km² of ice left in Venezuela


1910



1988



2008

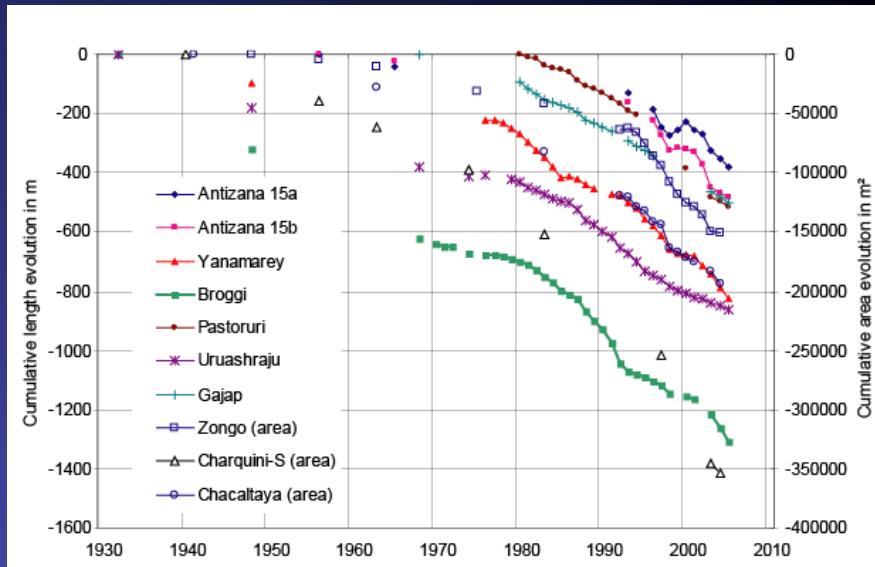


Photos courtesy Eduardo Carillo

Jahn [1931]; Schubert [1992, 1999]

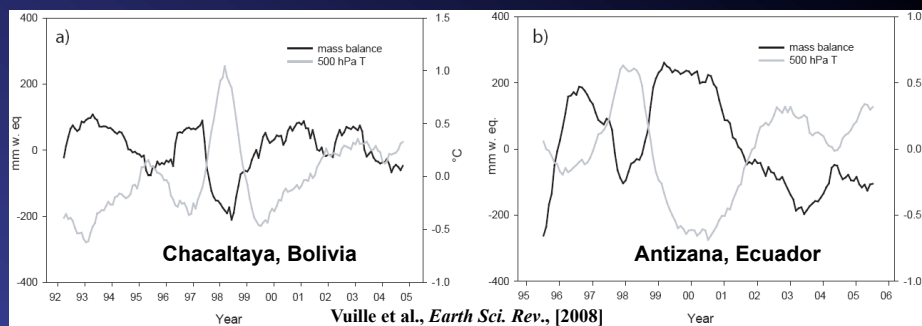


The retreat of 10 tropical glaciers in Ecuador, Peru and Bolivia



Vuille et al., *Earth Sci. Rev.*, [2008]

Glacier mass and energy balance



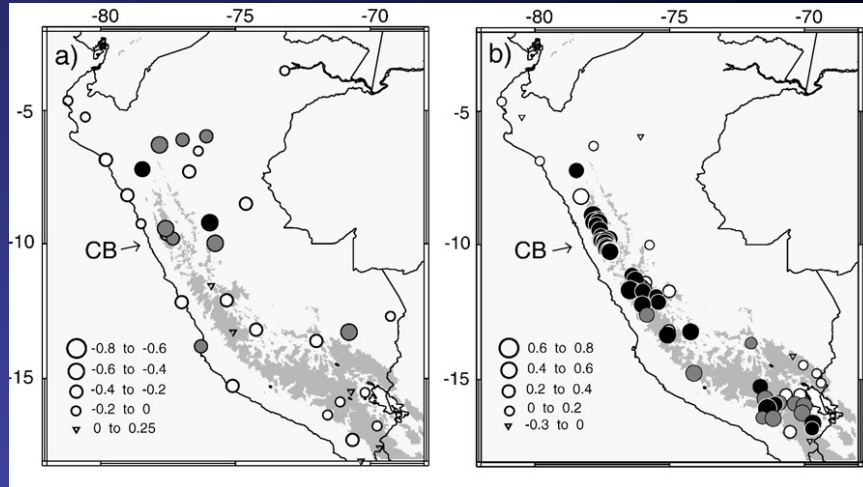
Vuille et al., *Earth Sci. Rev.*, [2008]

- Changes in cloud cover (net radiation is main energy flux measured on glacier surface)
- Changes in humidity (partitioning of available energy into melt and sublimation)
- Rate and timing of snowfall determines albedo
- Sensible heat flux is not main component of glacier energy balance, however integrates all above aspects through temperature

Sensitivity of glacier mass balance to temperature and precipitation in the Cordillera Blanca, Peru

Temperature

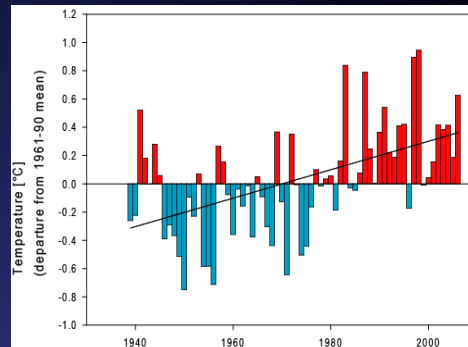
Precipitation



Gray circles: $p < 0.05$
 Black circles: $p < 0.01$

Vuille et al., *Global Planet Change*, [2008]

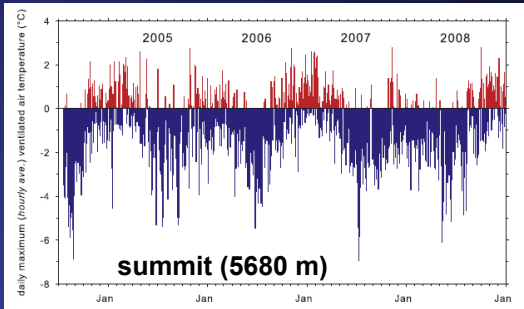
20th century temperature trends in the tropical Andes



Near-surface temperature
 increase of 0.68°C since 1939
 ($\sim 0.1^{\circ}\text{C decade}^{-1}$)

Vuille & Bradley, *Geophys. Res. Lett.*, [2000]
 Vuille et al., *Climatic Change*, [2003]
 Vuille et al., *Earth Sci. Rev.*, [2008]

Rising freezing line in the tropical Andes



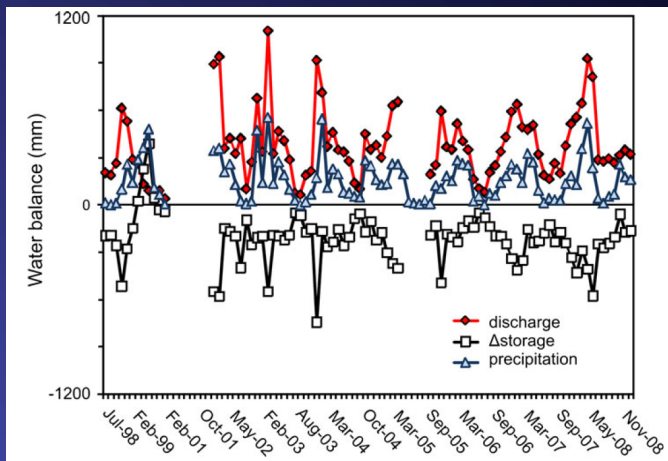
Daily maximum air temperature (hourly averages) on Quelccaya Ice Cap, Peru

Bradley et al., *Geophys. Res. Lett.*, [2009]



The impact of glacier retreat on runoff

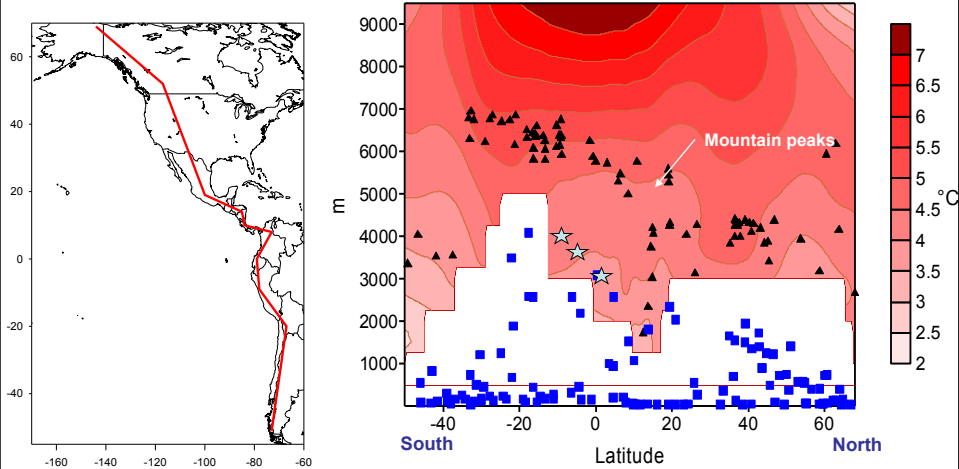
Monthly hydrologic mass balance at glacier Yanamarey (Cordillera Blanca, Peru)



Bury et al., *Climatic Change* [2011]

Part II: Future Projections

Option 1: Consider free tropospheric temperature change



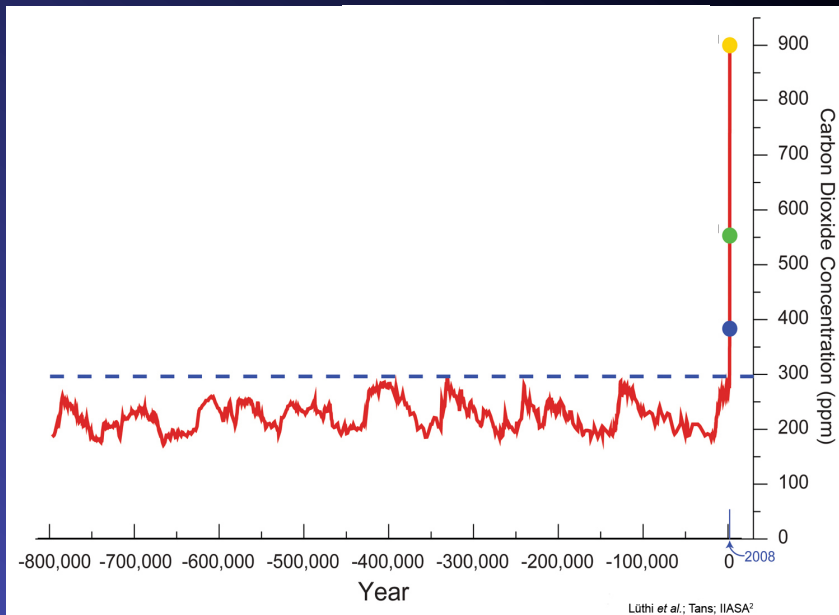
Projected change in temperature (1990-99) to (2090-99) along the American Cordillera, from Alaska to Chile (mean of 8 GCMs (IPCC AR4) scenario A2)

Bradley et al., *Science*, [2006]

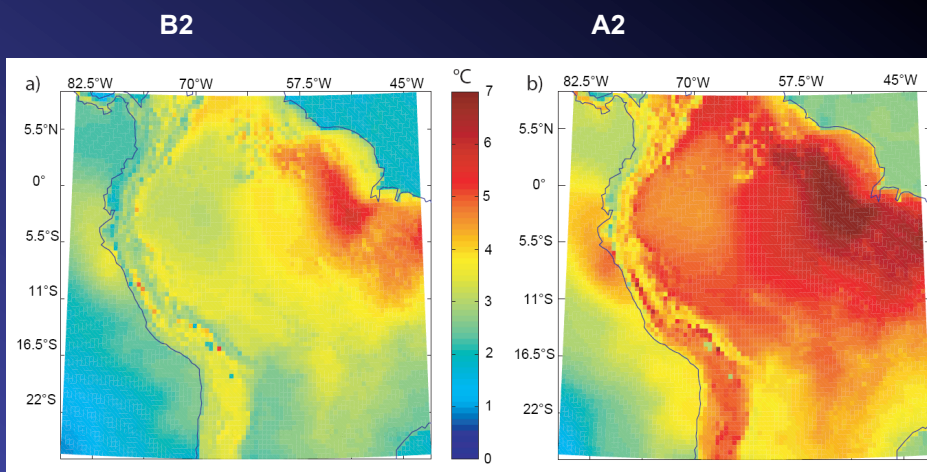
Option 2: Use of high-resolution regional climate models (RCM's)

- PRECIS RCM
- Had RM3, nested in HadCM3
- 50 km horizontal resolution
- Tropical South America (10° N-27° S; 86° W-44° W)
- Ctrl (1961-90), ERA (1957-2001)
- A2 (2070-2100): 15 billion people, 850 ppm of CO₂ by 2100
- B2 (2070-2100): 10.4 billion people, 550 ppm of CO₂ by 2100

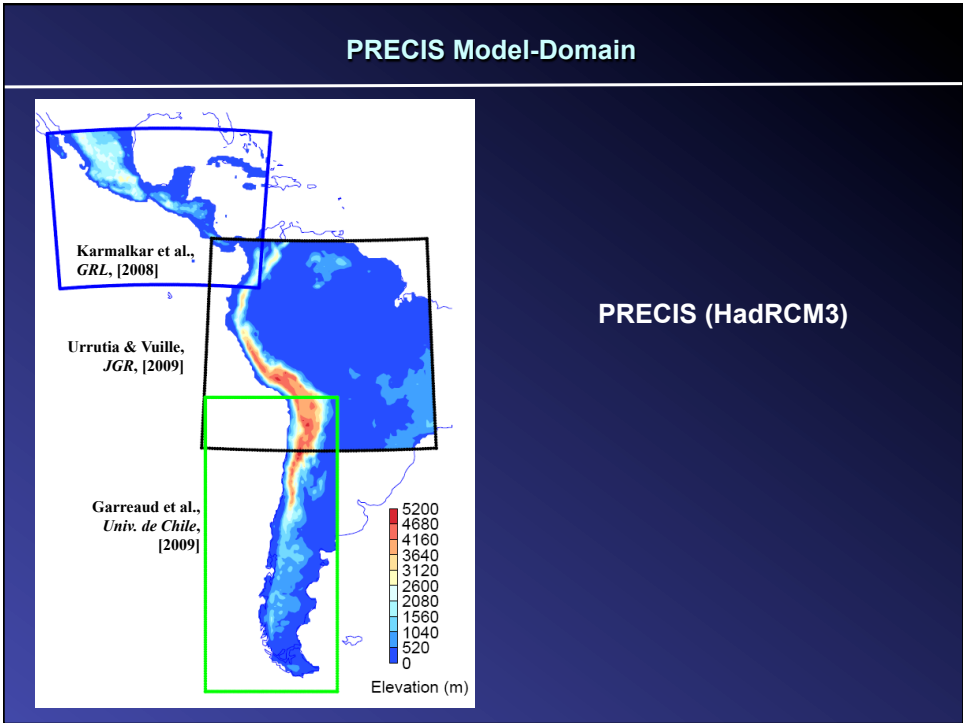
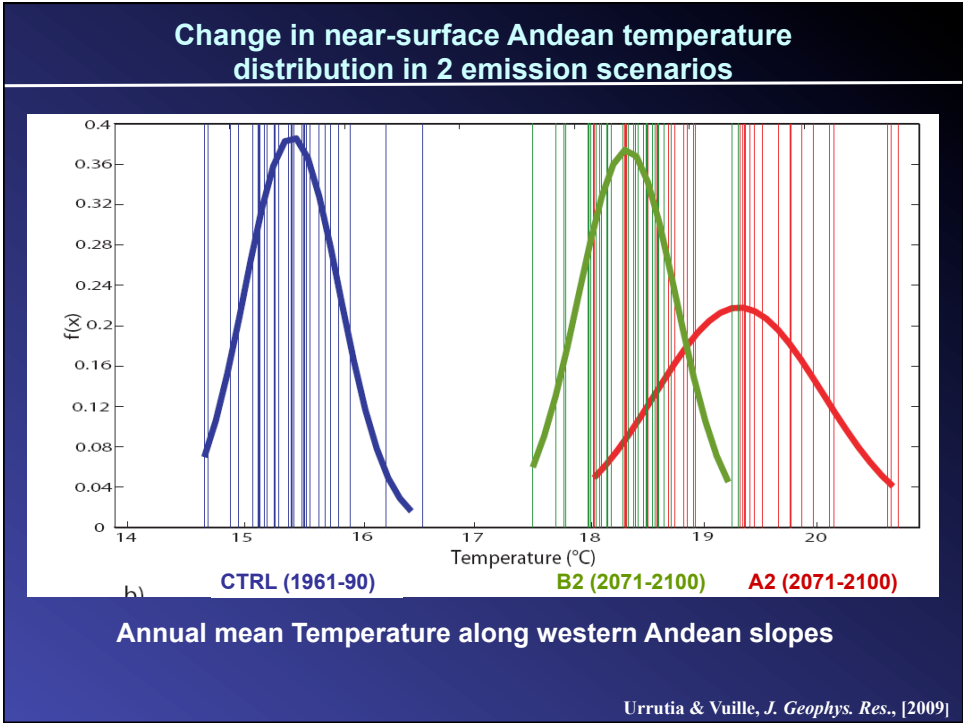
21st century GHG emissions in the context of the past million years



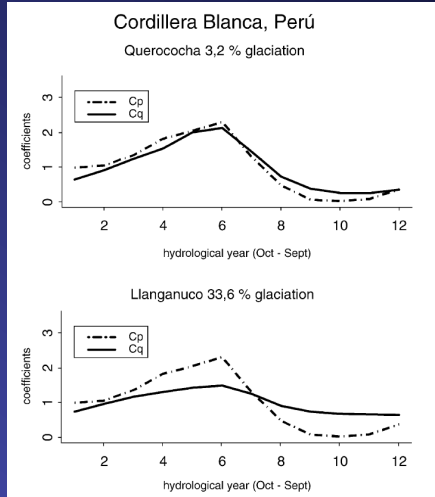
Annual mean temperature change for B2 and A2 (2070-2100) minus Ctrl (1961-90)



Urrutia & Vuille, *J. Geophys. Res.*, [2009]



The impact of glacier retreat on runoff



Kaser et al., *J. Hydrol.*, [2003]

Relevance of this process:

- most important in regions such as Peru, where rivers drain into seasonally arid lowlands

Kaser et al., *PNAS*, [2010]

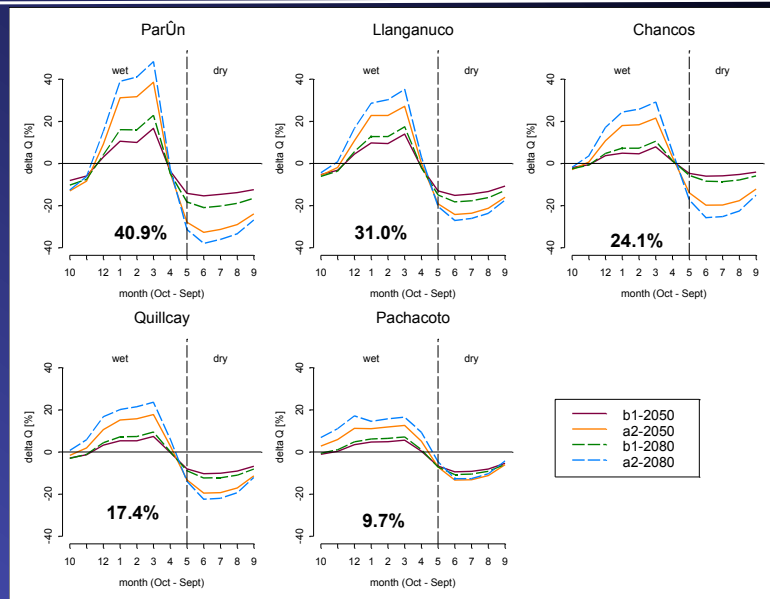
- less relevant in inner tropics where paramos can take on regulating function and where precipitation is less seasonally biased

Buytaert et al., *Earth Sci. Rev.* [2006]

- similar processes at play in extratropical Andes, but seasonal snow cover of higher relevance (snow cover is not a significant seasonal storage term in the tropics)

Wagnon et al., *J. Geophys. Res.*, [2009]

Simulated changes in runoff (relative to 1961-90) in different catchments of the Cordillera Blanca



Juen, *PhD Univ. Innsbruck*, [2006]; Vuille et al., *Earth Sci. Rev.*, [2008]

Runoff change in % in 2050 and 2080 for B1 and A2 scenarios

Adaptations in water use and management

- **Technological Adaptation**

- creation of water reservoirs
- exploit new water resources
- conservation measures
- construction of water treatment plants

- **Scientific strategies**

- improve monitoring network
- better assimilation of new data systems (GIS, remote sensing)
- advance regional climate projections (downscaling)

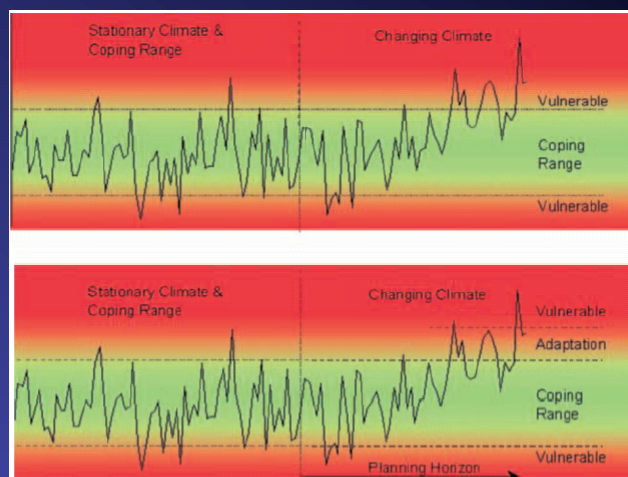


- **Policy instruments**

- regional training and capacity building
- improve collaboration between scientists, stakeholders, water managers...
- scientific results need to be accessible and translated into language that is understandable by non-scientists

→ **Goal must be to reduce the vulnerability and increase the resilience of water users**

Towards a sustainable development – Adaptations for future generations are needed



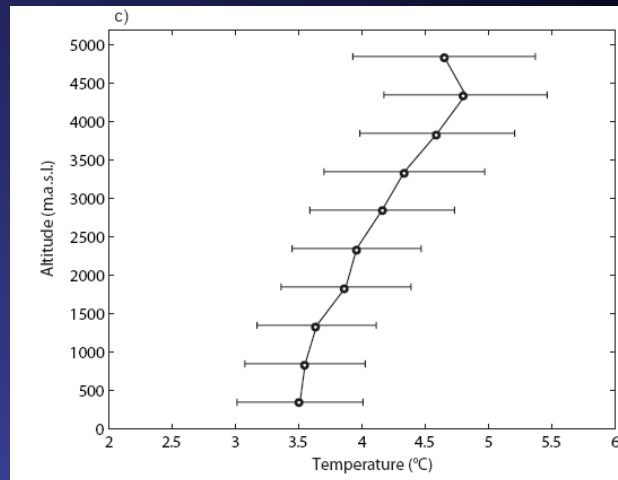
Jones and Mearns, [2004]



Photo: M. Vuille

→ **Goal must be to reduce the vulnerability and increase the resilience of water users**

Temperature change as a function of elevation



Temperature Change (A2-Ctrl) along western Andean slopes

Urrutia & Vuille, *J. Geophys. Res.*, [2009]