Andean cryospheric observation from a transdisciplinary perspective

2016 Snow Watch, Ohio State, 14 June

THE OHIO STATE UNIVERSITY
BYRD POLAR RESEARCH CENTER
A Century of Geography
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Bryan G. Mark
Professor of Geography
Byrd Polar & Climate Research Center
Ohio State University

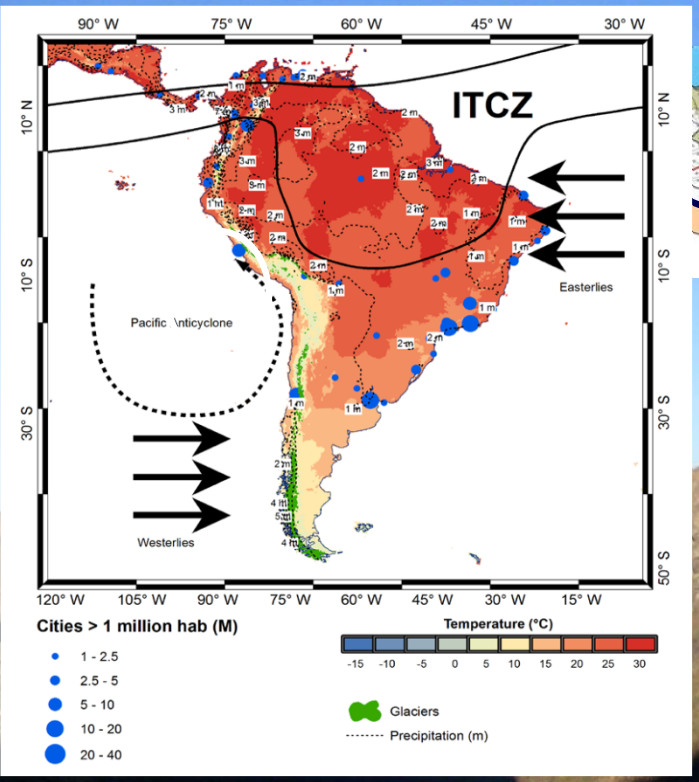
TARN
TRANSDISCIPLINARY ANDEAN RESEARCH NETWORK
RED DE INVESTIGACIÓN TRANSDISCIPLINARIA ANDINA

- Michel Baraer (ETS)
- Jeffrey McKenzie, Lauren Somers (McGill)
- Alfonso Fernandez (Concepcion, Chile)
- Laura Lautz, Robin Glas, Emily Baker (Syracuse)
- Robert Hellström (Bridgewater State)
- Ken Young, Molly Polk (UT Austin)
- Mark Carey (U Oregon)
- Jeff Bury (UCSC)
- Ryan Crumley, Anne Nolin (Oregon State)
- Jeff La Frenierre (Gustavus Adolphus)

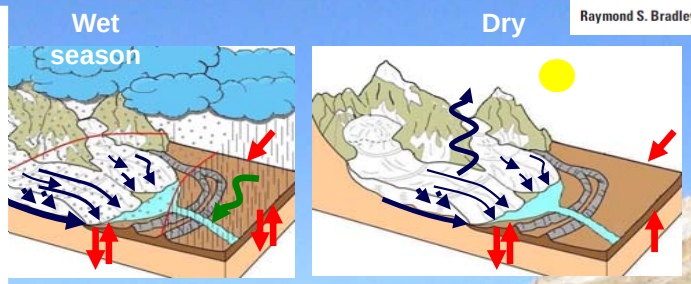
- Thomas Condom (IRD, France)
- David Porinchu (U Georgia)
- Sarah Fortner (Wittenberg)
- Kyung In Huh (Pomona)
- Ing. Alejo Cochachin (Unidad de Glaciologia y Recursos Hidricos ANA)
- Adam French (IIASA, Austria)
- Ing. Ricardo J. Gomez (Parque Nacional de Huascaran)
- Chris Hopkinson (Lethbridge, Canada)
- Pablo Lagos (Instituto Geofisico del Peru)
- Rolf Weingartner (Bern, OCCR)

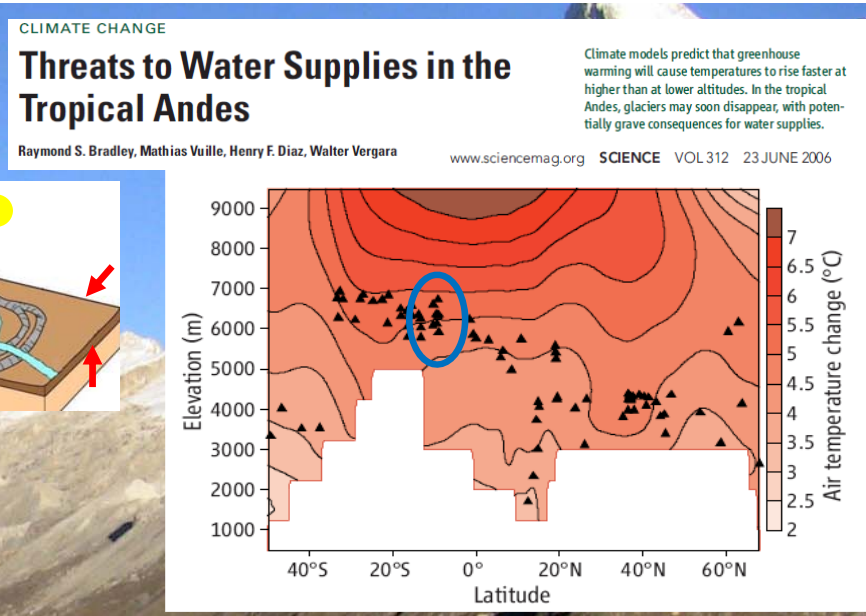
Oliver Wigmore (PhD)
Gabriel Zeballos Castellon (PhD)

Andean cryosphere - changing climate



A. Fernandez, 2014, PhD thesis





- Complex climates (latitude)
- Variety of glacier types (e.g. small mountain glaciers, large tidewater glaciers)
- Different connection to people
- Tropical glaciers – sensitive, variable, impactful

Glacier distribution

82% Glaciers 10% Total area

8% Glaciers 7% Total area

6.2% Glaciers 12% Total area

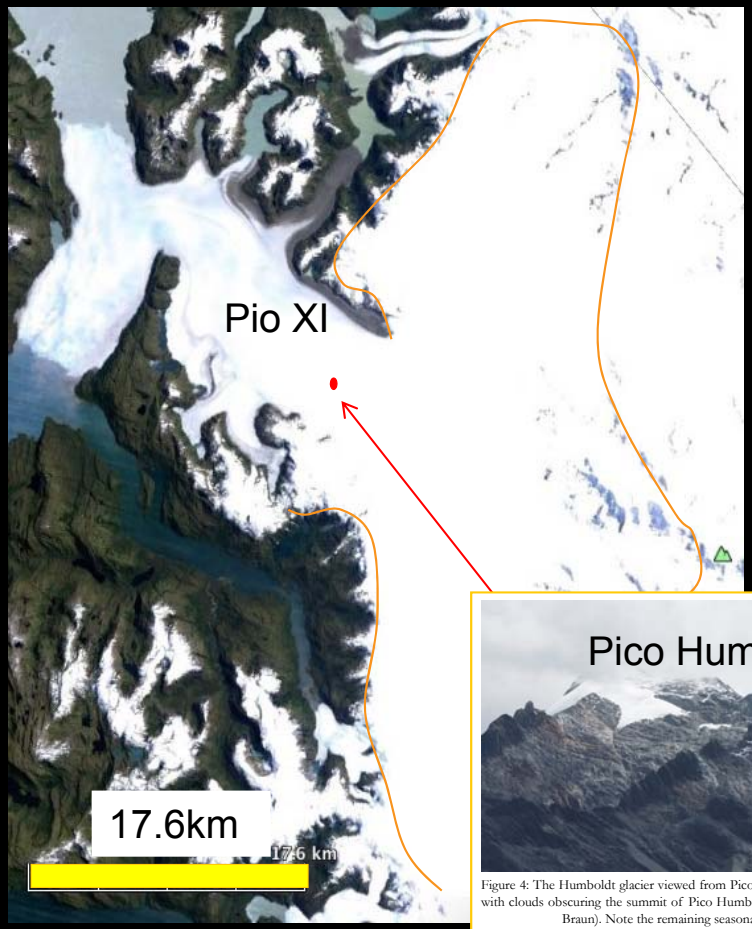
2.2% Glaciers 8% Total area

1.4% Glaciers 21% Total area

0.2% Glaciers 42% Total area

Data after WGMS and RGI

Glacier types



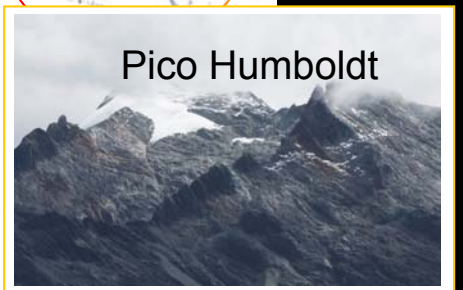


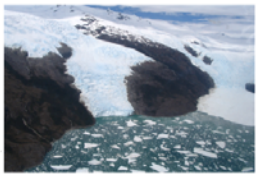
Figure 4: The Humboldt glacier viewed from Pico Espejo on 4 February 2009 with clouds obscuring the summit of Pico Humboldt (photograph by Carsten Braun). Note the remaining seasonal snow cover.

Chimborazo, Ecuador

Cord. Central, Peru

Sierra Velluda, Chile

Patagonia, Chile



Limited observations

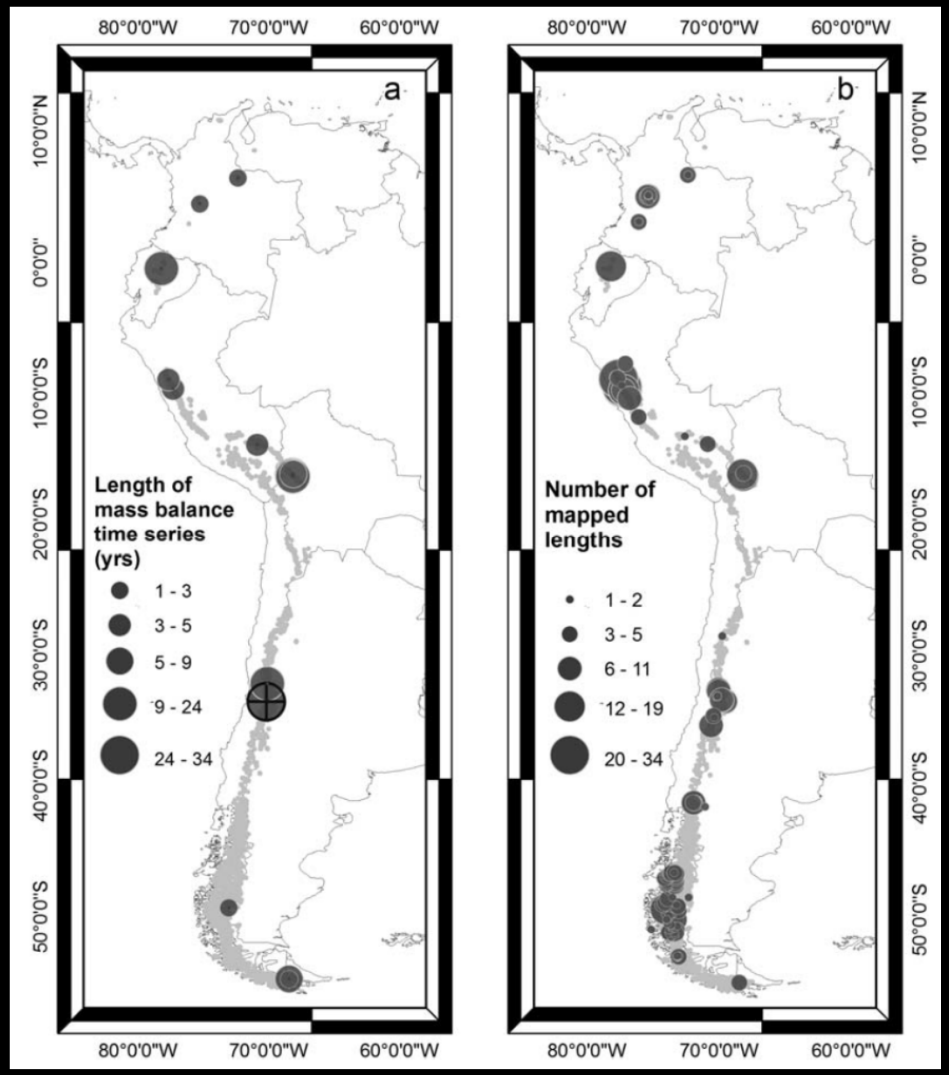
- Of 27,500 Andean glaciers in RGI, only 1 has been observed continuously for >30 years
- Vast majority are less than 10 yr
- Most began after 1990's or were only short duration

AGU PUBLICATIONS

Journal of Advances in Modeling Earth Systems

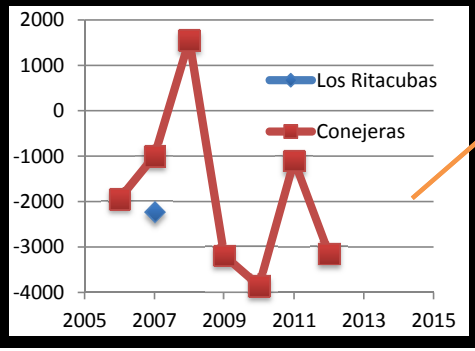
Modeling modern glacier response to climate changes along the Andes Cordillera: A multiscale review

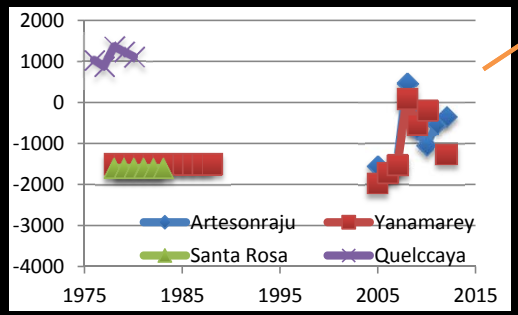
Alfonso Fernández[1,2,3] and Bryan G. Mark[1,2]

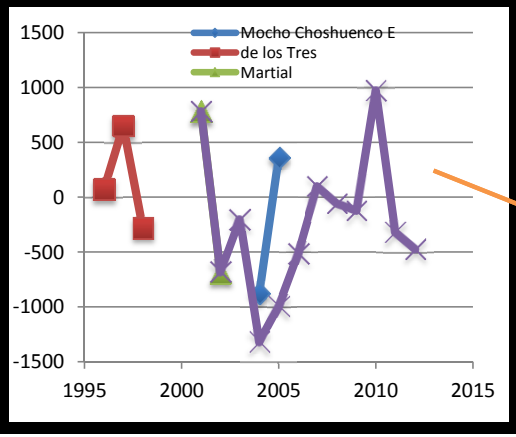


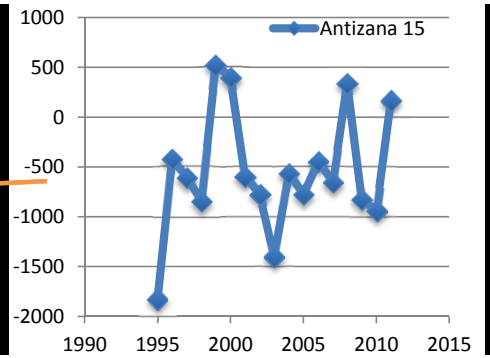
Lack of continuous observations

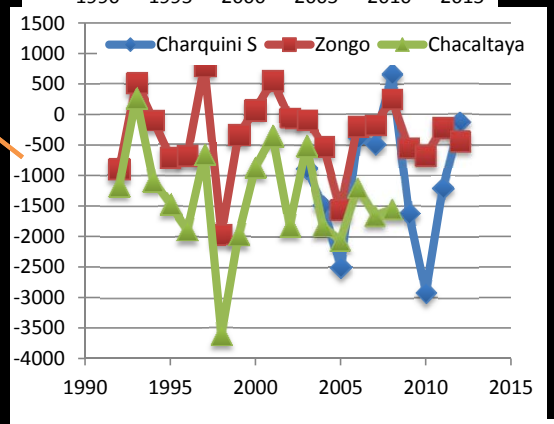
mmwe

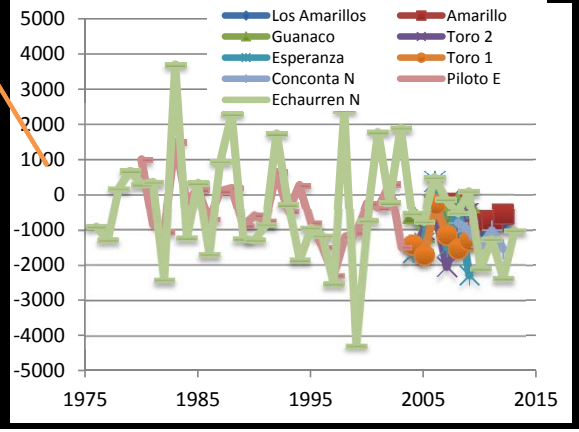












Arid coast & hydraulic interdependence

Coastal Agriculture & Populations

Rely on Glacial-fed Rivers

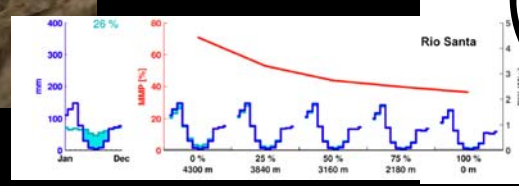
Only 2% of all the water resources in Peru are available for the arid coast

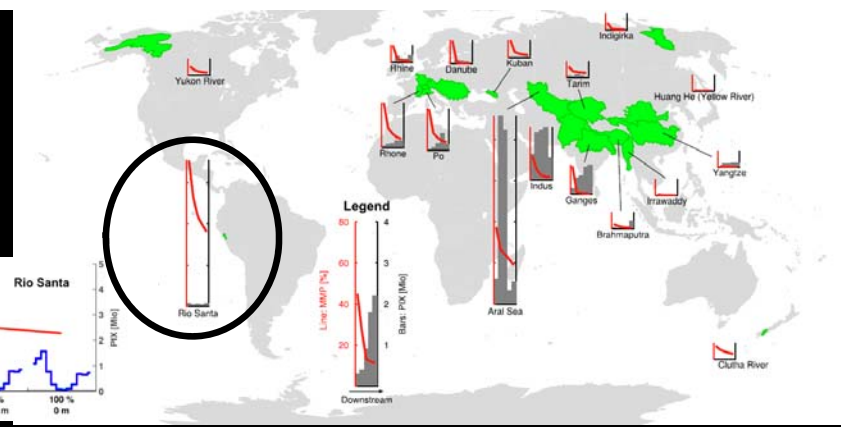
- Glaciers buffer streams
- Small human dependence given basin population densities, distance. (Valid scale?)

Contribution potential of glaciers to water availability in different climate regimes

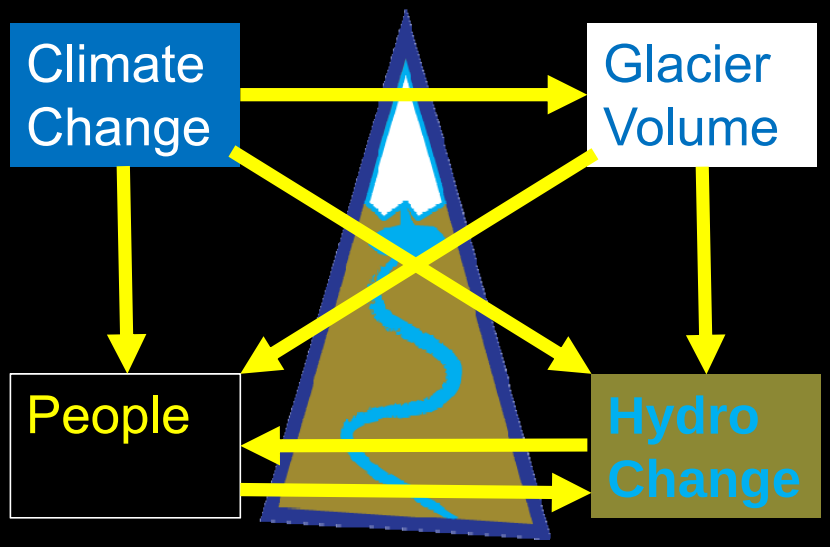
PNAS | November 23, 2010 | vol. 107 | no. 47 | 20223–20227

Georg Kaser, Martin Großhauser, and Ben Marzeion[1]





Evaluating hydro-social vulnerability



Dynamics of Coupled Human Natural Systems:

"Hydrologic Transformation and Human Resilience to Climate Change in the Peruvian Andes"

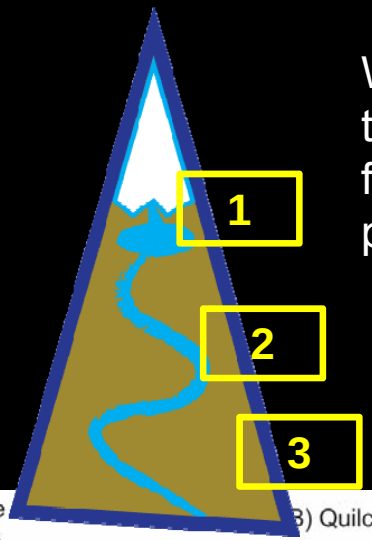
Physical & Human Geography
Environmental Sci
Biogeography
Hydrogeology
Engineering
History

Who is vulnerable, where, and why?

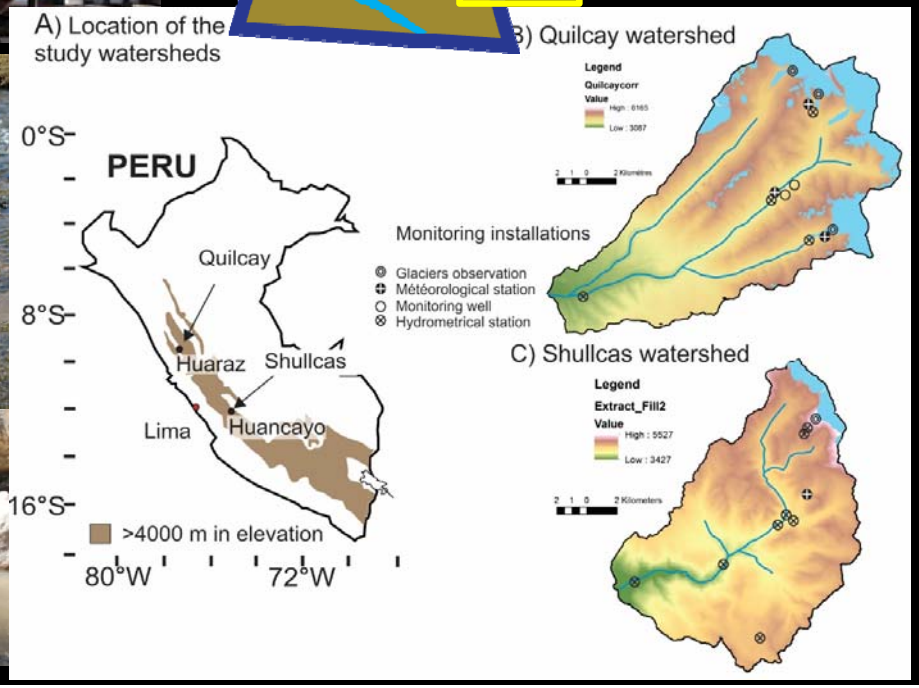
- How much volume are the glaciers losing?
- How is downstream hydrology changing in the watershed?
- What impact does this have on people?

Comparative watersheds
Mixed methods

- Integrated human & physical geography
- Field obs & modeling
- Focus on patterns & process
- Crossing scales, from ice to people
- High resolution remote sensing
- Embedded sensors "sustainable tech"
- Institutional partners



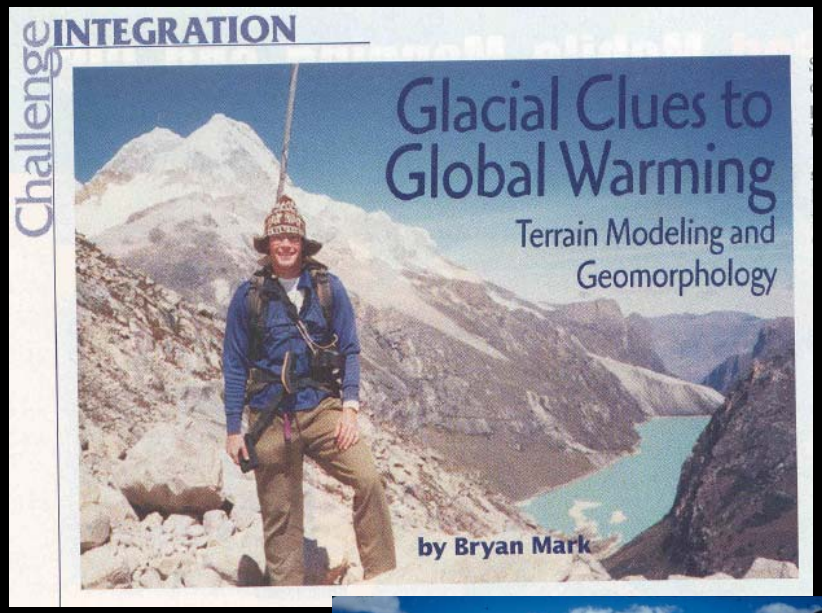
Waterscapes: tracing water from glaciers to people

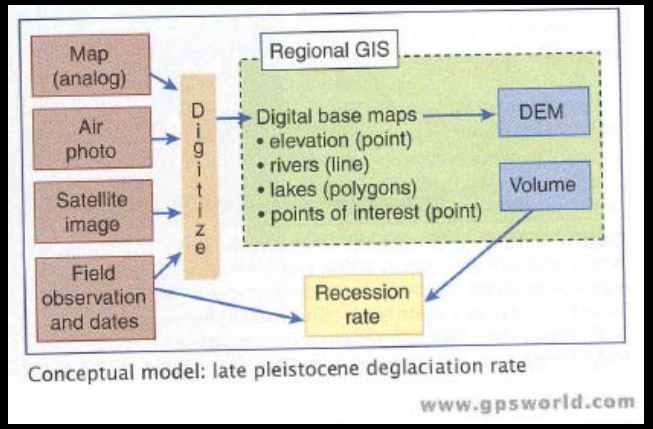


Basic approach

1. Measuring glacier changes
   - Volume loss as surface elevation change
2. Evaluation of hydrological changes
   - Discharge trends (historical to modern)
   - New embedded measurements
   - Assimilation & modeling
3. Modeling glacier-climate over time
   - Glacier mass balance & regional climate
   - Downscaling climate reanalyses via WRF

Estudios doctorado *(fines de siglo XX)*

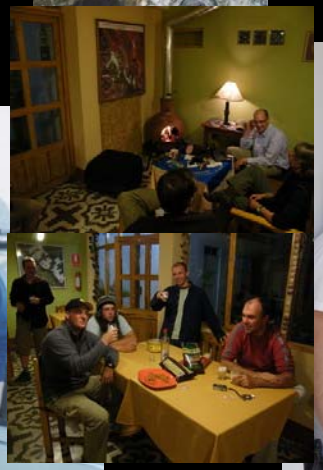




Other international collaboration

“Ciencia familiar”

Alcides Ames (1942-2007)



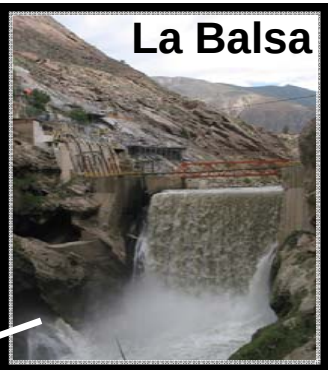
1998 “Mis familias”

2012 B&B My House
http://micasahuaraz.jimdo.com/

Santa River watershed

12,200 km^2
Different water demands

Desert agricultural irrigation ttp://www.fao.org/



Cañón del Pato hydroelectric plant
Photo: Mark Carey

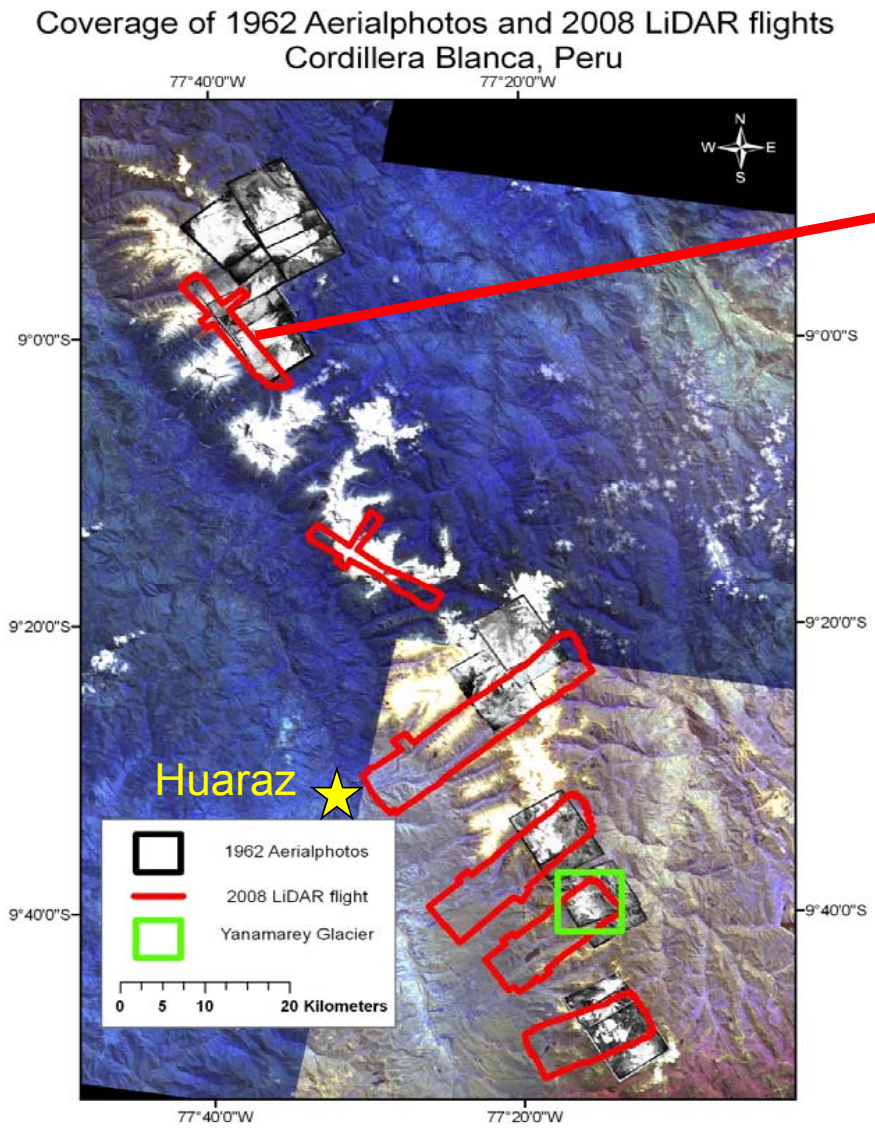
Cordillera Blanca

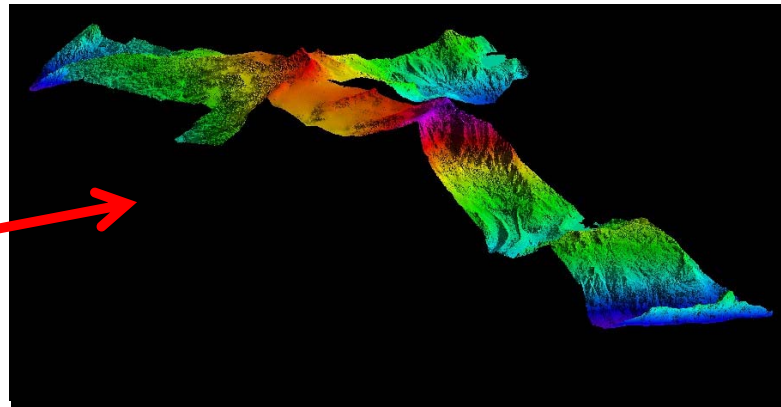
Yanamarey glacier

Most glacierized tropical range

Rapid glacier recession

Yanamarey glacier





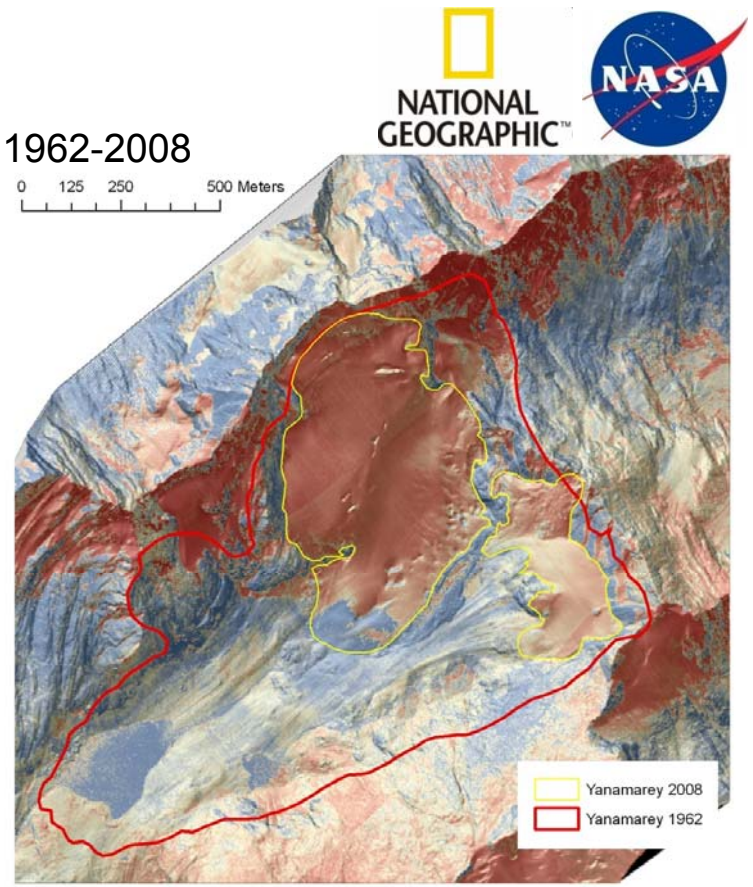
2008 LiDAR Survey

Cordillera Blanca

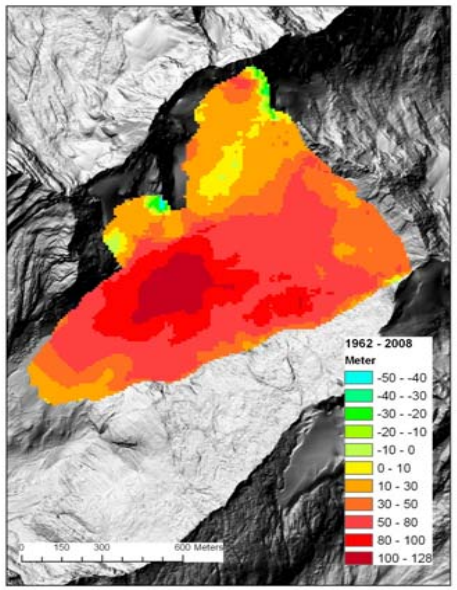
Total area covered (564 km^2). This represents 71 % of the total requested coverage of 792 km^2

Stereo-paired aerial photographs (1962 epoch) for glacier surface elevation mapping (n=23)

VOLUME changes (1962-2008)



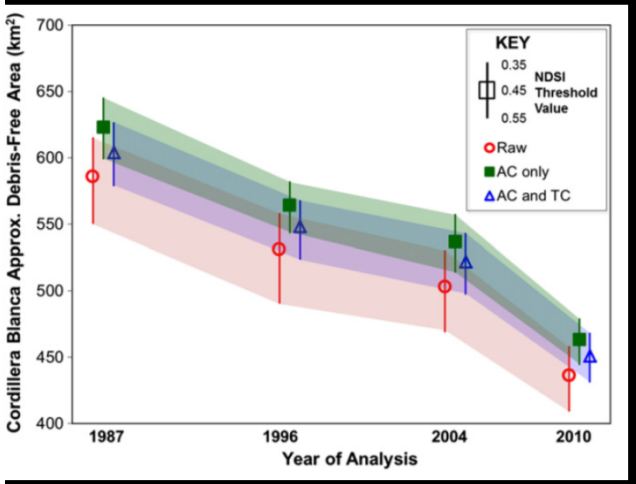
Huh et al., 2012. “Changes of topographic context of the Yanamarey glaciers in the Tropical Peruvian Andes." *International Association of Hydrological Sciences* 352, 333-336.



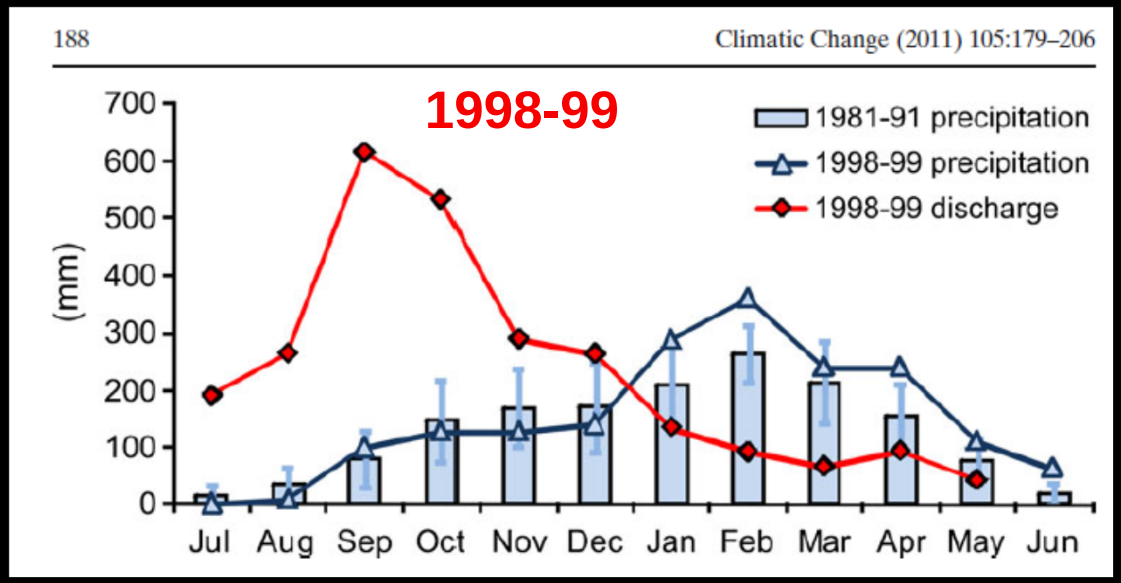
Glacier change:

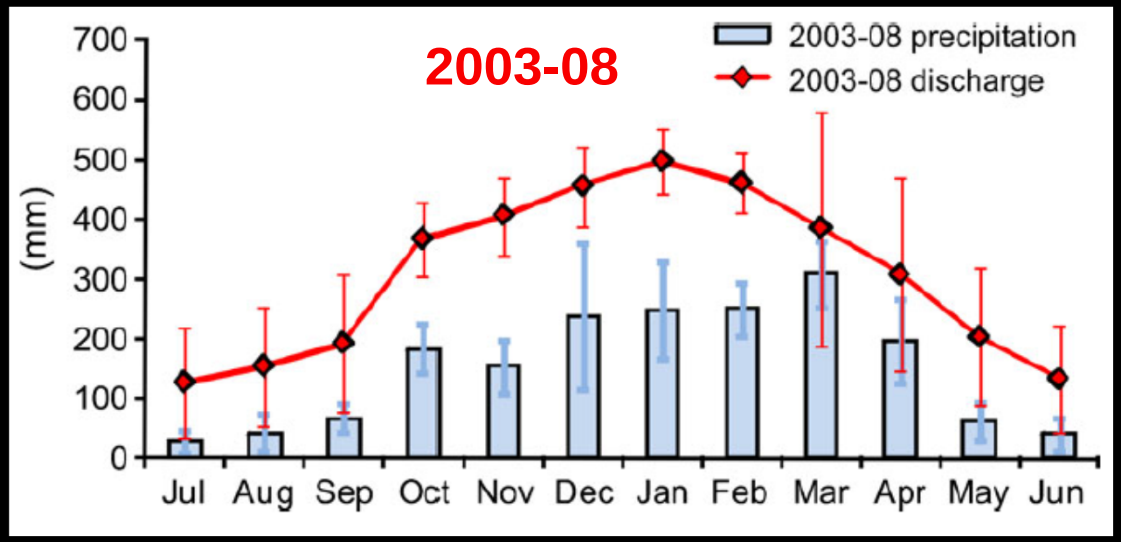
(1) Volume loss 2-12 x > predicted

(2) Accelerating recession over the Cordillera Blanca: 25% since 1987

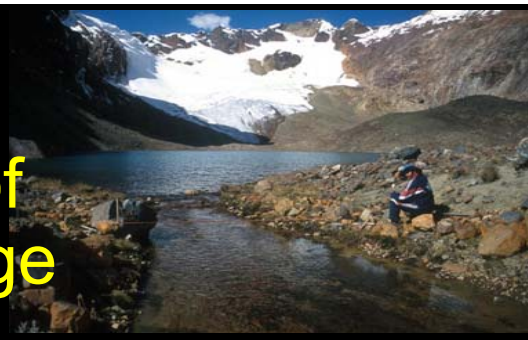


Burns & Nolin, 2014, *Remote Sensing of Environment* 140, 165–178.





(1) Shifting seasonality of YAN discharge



Discharge (Q) and precipitation (P)

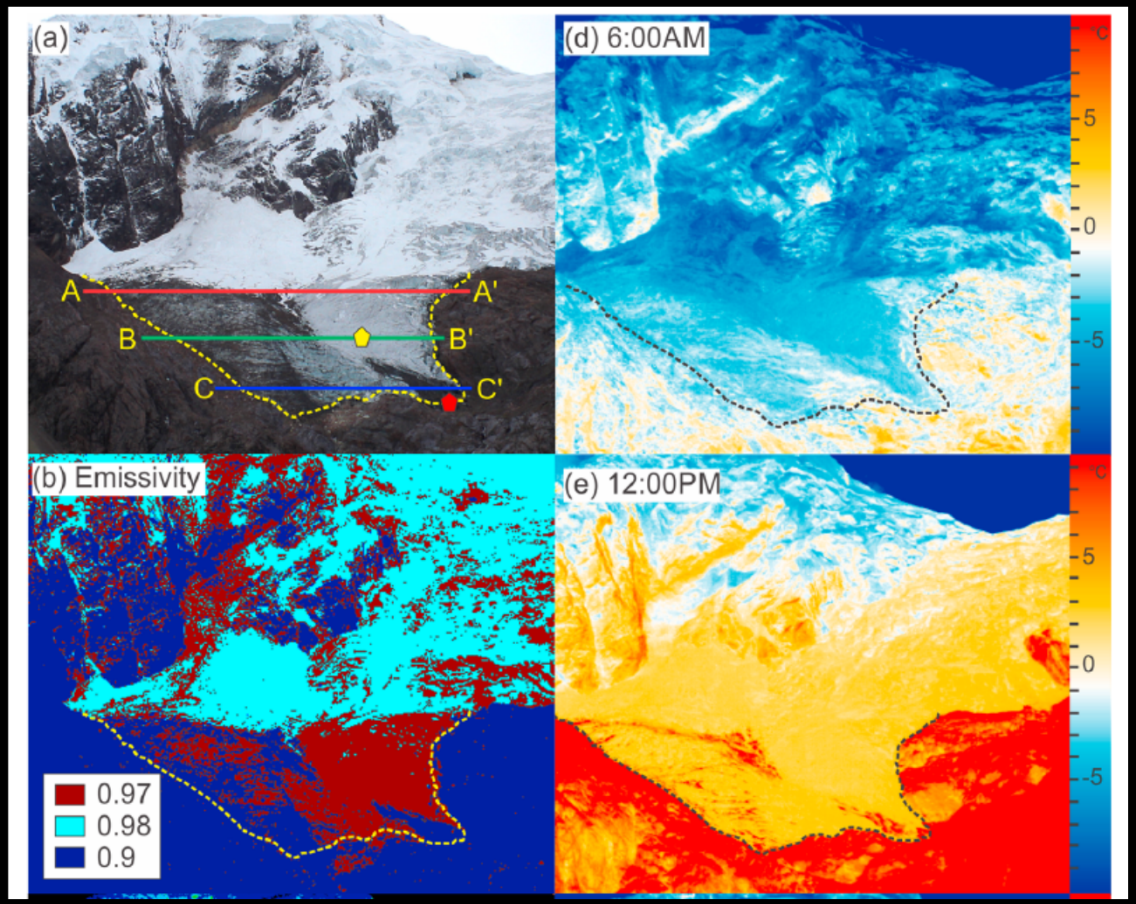
Area normalized (mm)

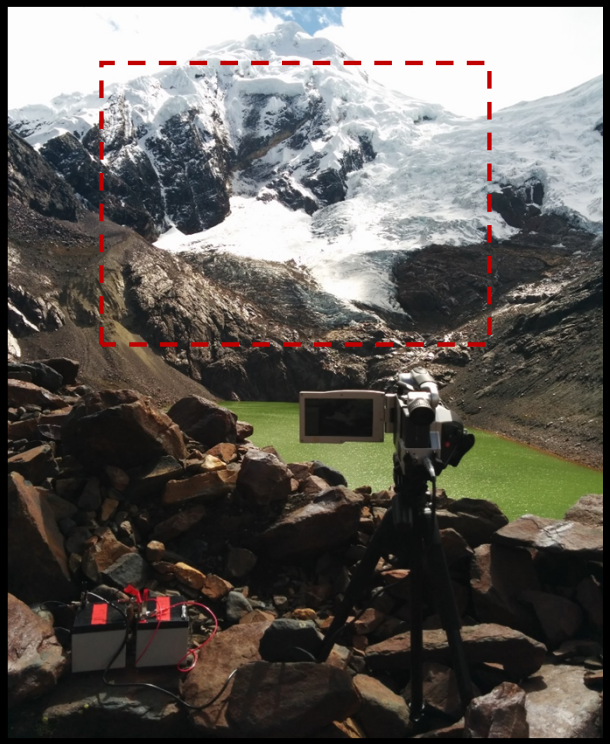
Bury et al., 2011, "Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru." *Climatic Change*, 105(1-2): 179-206

Glacier Headwaters

Photo: Oliver Wigmore, OSU

High resolution processes at glacier





Aubry-Wake, et al., 2015, Measuring glacier surface temperatures with ground-based thermal infrared imaging, *Geophys. Res. Lett.*, 42, 8489–8497.

(2) Current Hydrology Research Questions

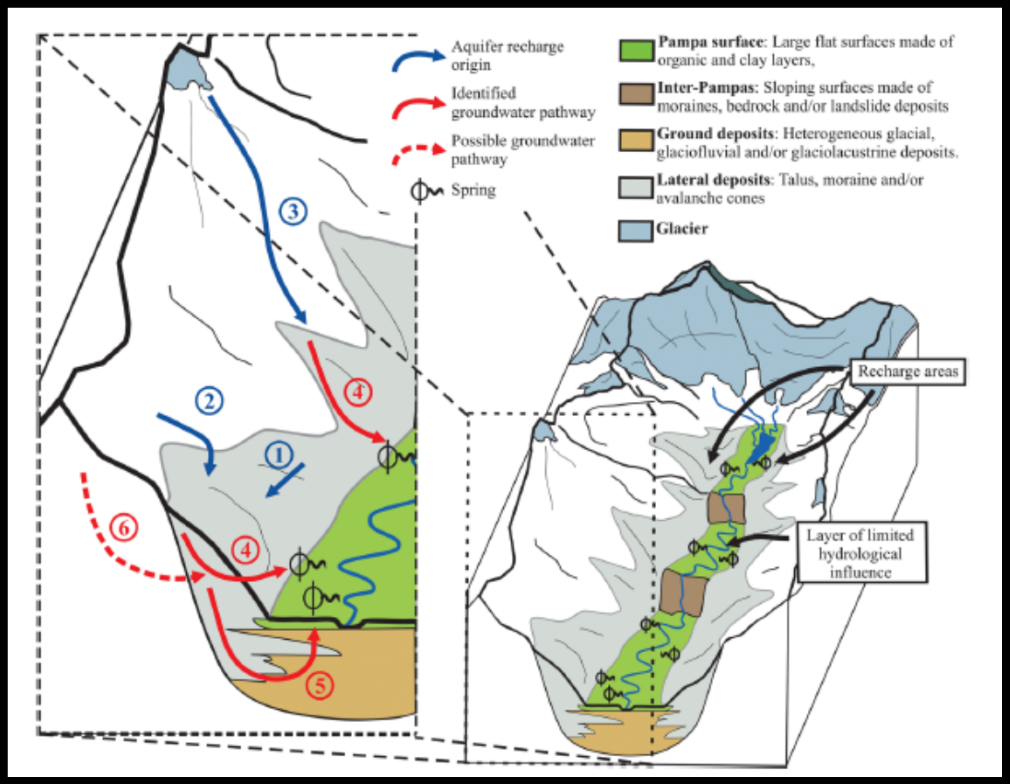
Glacier melt-water is important. How important is groundwater?

How does the groundwater system work?

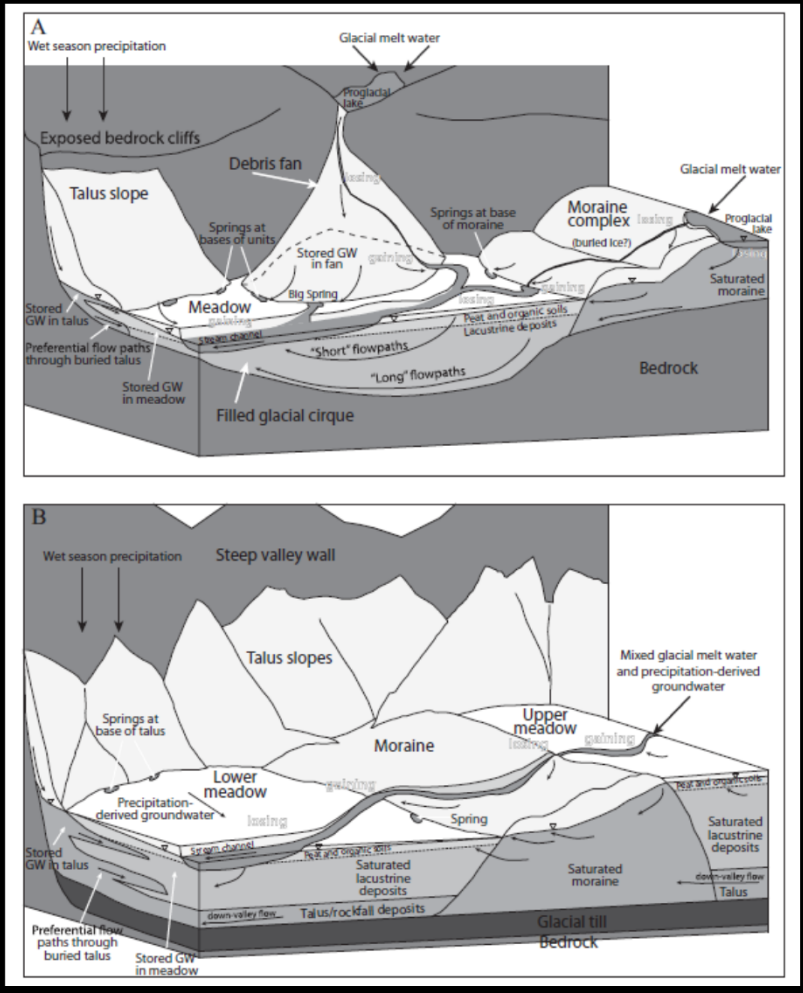
Methods

Proglacial valley processes

Hydrochemical, heat balance, and tracing show:
(1) Importance & (2) complexity of ground – sfc water

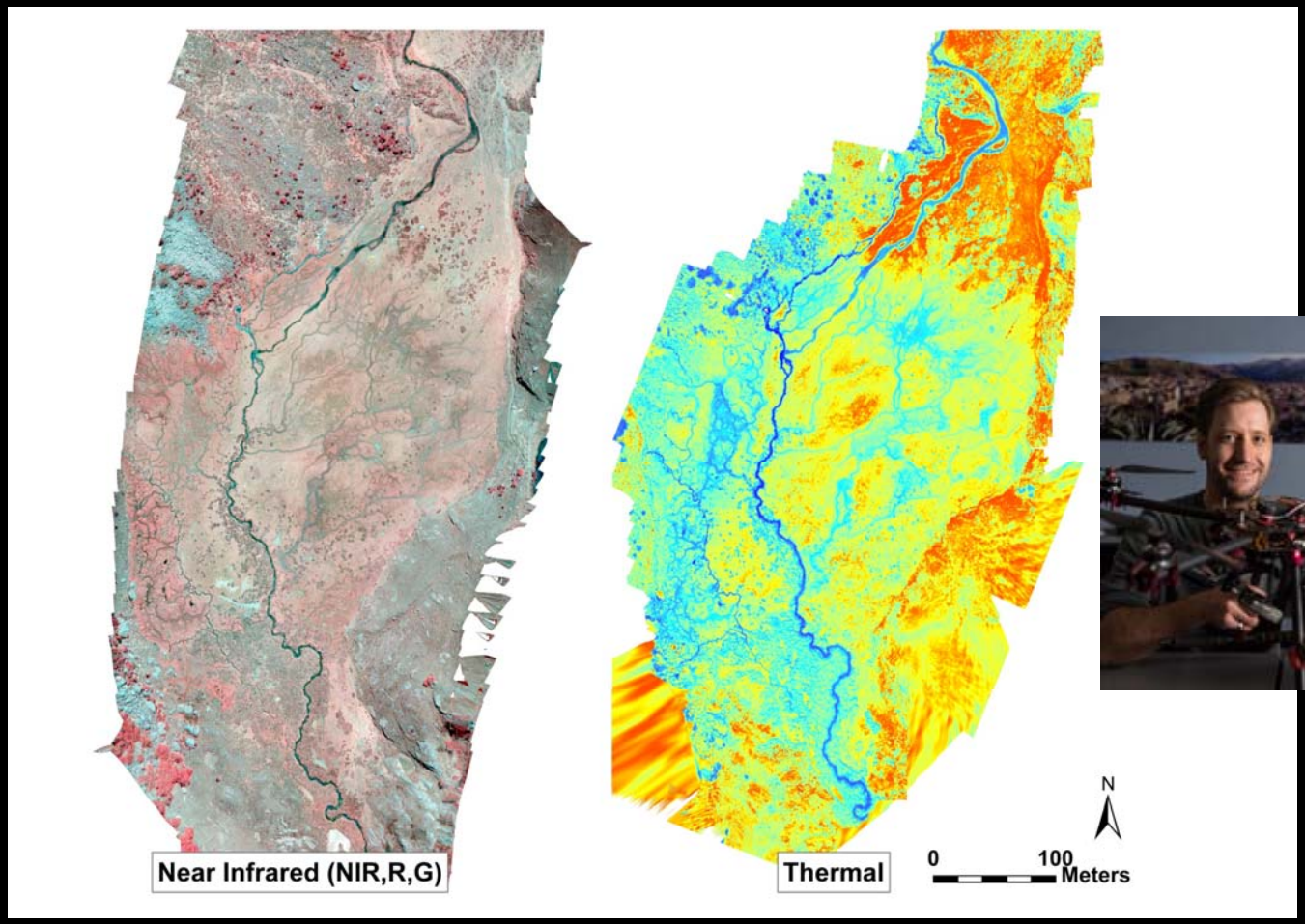


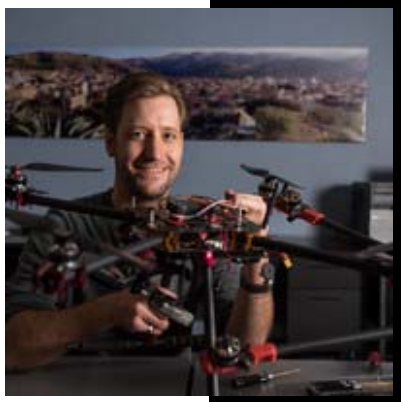
Baraer et al., 2015, "Contribution of groundwater to the outflow from ungauged glacierized catchments..." *Hydrol. Process*. 29, 2561–2581.



Gordon et al., 2015, "Sources and pathways of stream generation in tropical proglacial valleys of the Cordillera Blanca, Peru" J. *Hydrol.* 522, 628–644.

Proglacial valley: higher resolution view with drones

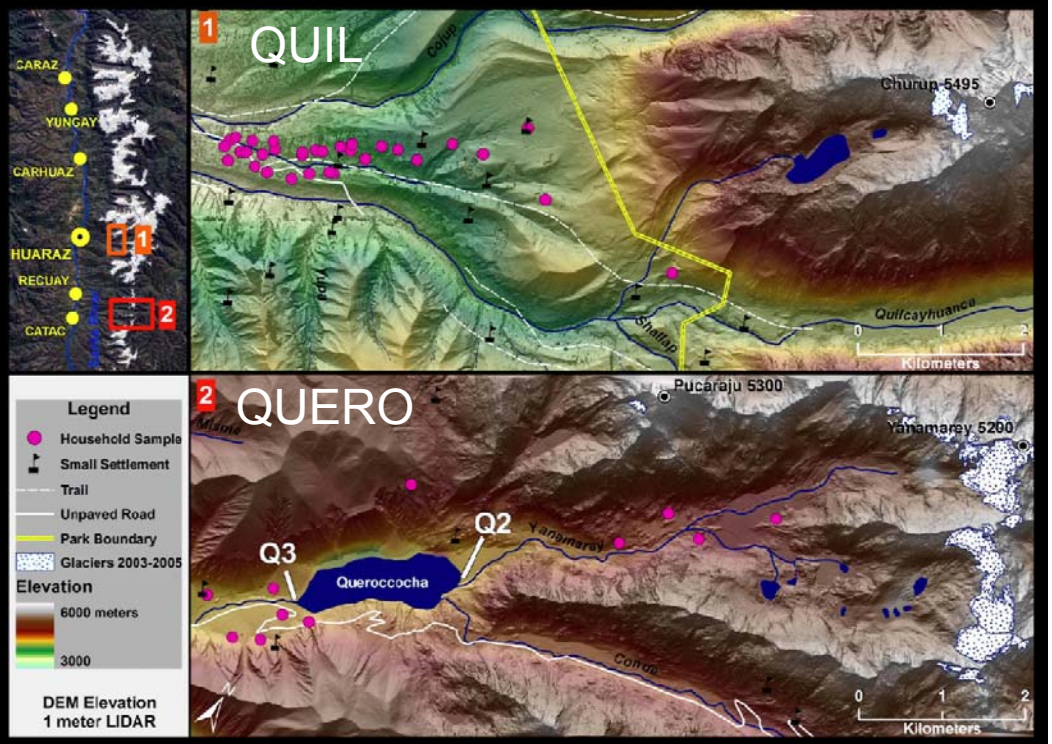




- UAV Multispectral mapping at 10cm resolution
- Tracing surface hydrology
- Spring mapping
- Vegetation health
- Soil moisture storage

https://www.youtube.com/watch?v=ERBBG4IaoNo&list=PL85bdQbcuF0RU9XdBT6Icnw-wE2wVK1A7&index=17

Livelihoods are natural resource dependent, diverse



Type of activity	Description and variety	QUER (percentage of households)	QUIL (percentage of households)
Livestock	Cattle, sheep, pigs, horses, guinea pigs, burros	85	78
Agriculture	Potatoes, olluco, oca, mashua, corn, wheat, barley, oats, quinua, beans, herbs	68	100
Agroforestry	Eucalyptus, pine, quenual (*polylepis*), capuli (*Prunus serotina*), colle (*Buddleja coriacea*)	68	72
Commercial	Livestock, agricultural products, market, prepared food	45	78
Manual labor	Temporary agricultural labor, carpentry, manufacturing	38	40
Tourism	Guiding, animal caretaker, burro rental, cook, boat rental	25	27
Dairy products	Milk, cheese, eggs	15	9
Artisanal	Hand spun fabrics, clothing, ceramics	15	3

Bury, Mark et al., 2011, "Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru." *Climatic Change*, 105(1-2): 179-206

Emerging Vulnerabilities-Shifting Water Variability

- QUERO-93% of respondents noted that over the course of the past 10 years (ranging from 3-10 years) water supplies have been decreasing during the dry season
  - Still enough for human consumption
  - Pressure on municipal water system
  - Agriculture and Livestock
    - Canal levels dropping
    - Pasture health and productivity
    - Fish stocks

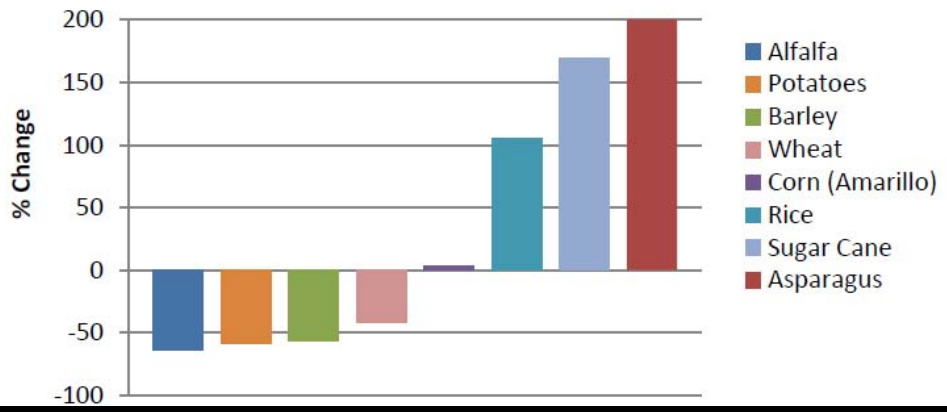
Emerging Vulnerabilities-Increasing Weather Extremes

- QUERO-95% of respondents indicated that significant and often extreme shifts in temperature variation, precipitation patterns and seasonal change have been occurring with greater frequency and intensity
  - Human impacts
    - Health “cold until the bones hurt”
    - Freezing events delay work
  - Agriculture and Livestock
    - Crop drying, frosts, winds (91 percent of respondents)
    - Rainfall shifts, planting season uncertainties, harvest damages
    - Animal health
      - New diseases, weakening

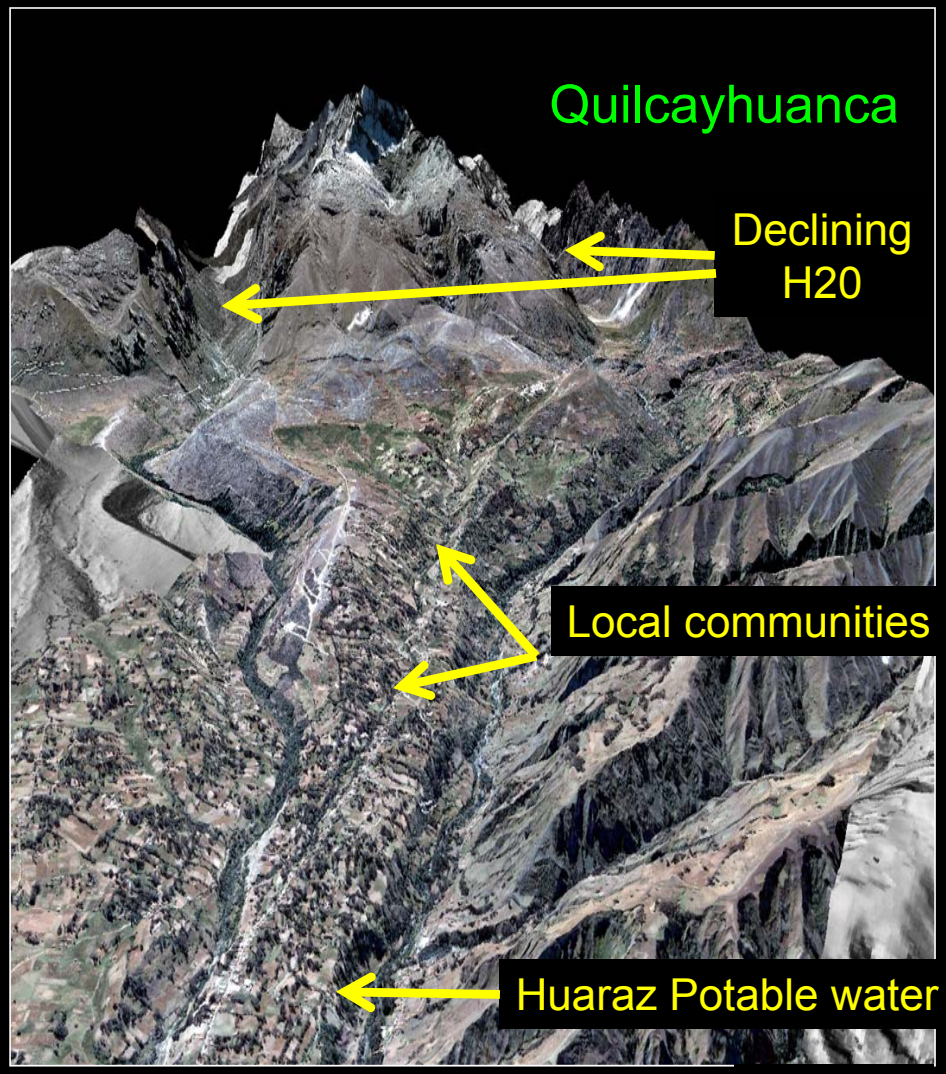
New resource struggles

- Spatial rescaling of access & institutional influence
- Governance struggles
- Scarcity struggles

Agricultural production, Ancash, Peru, 1960-2010

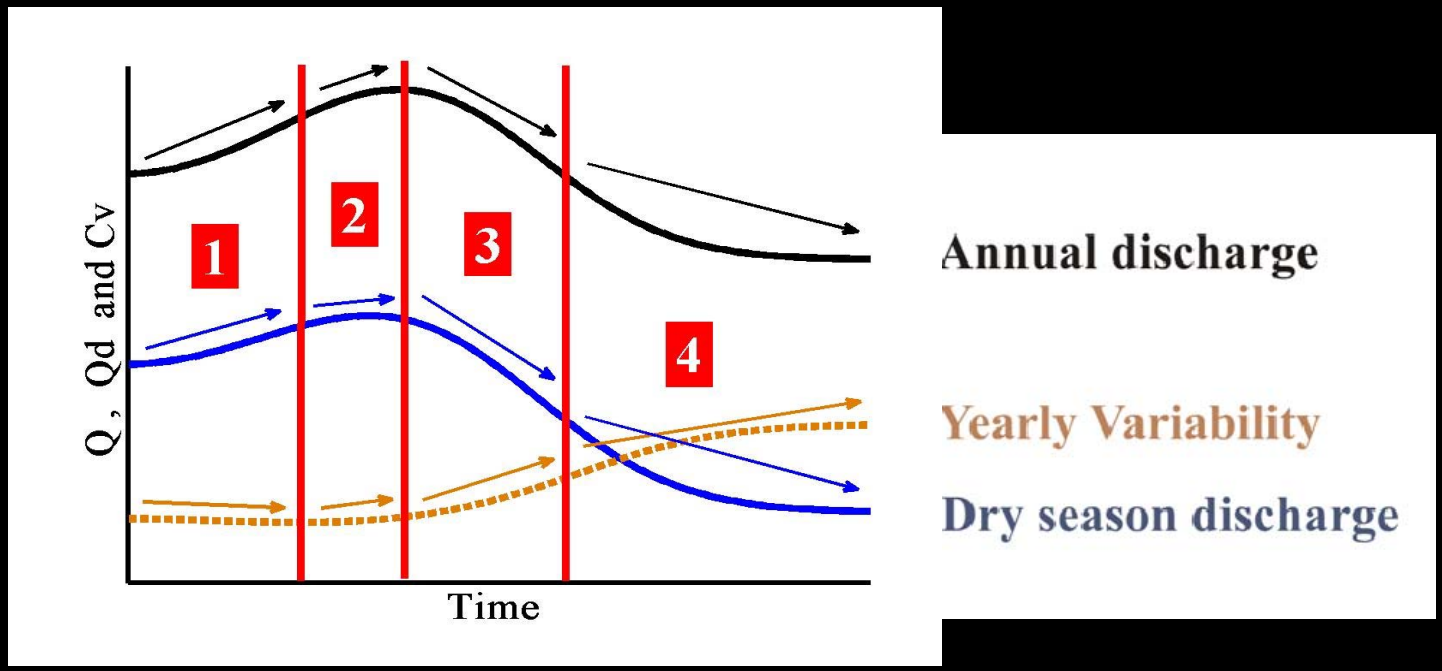


Bury, Mark et al., "New Geographies of Water and Climate Change in Peru: Coupled Natural and Social Transformations in the Santa River Watershed," *Annals of the Association of American Geographers 103, no. 2 (2013): 363-374.*



OSU LIDAR

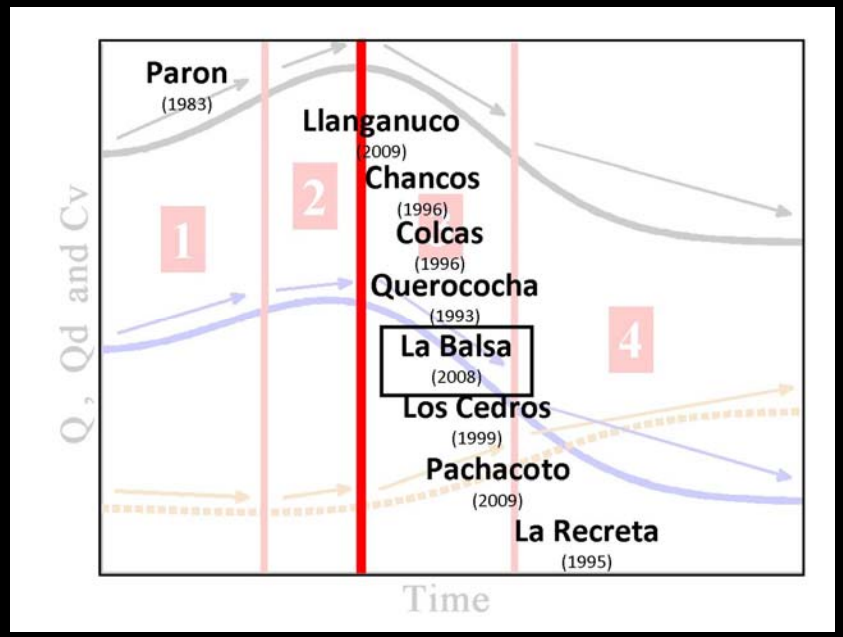
Hydro transformation: Passing “peak water”



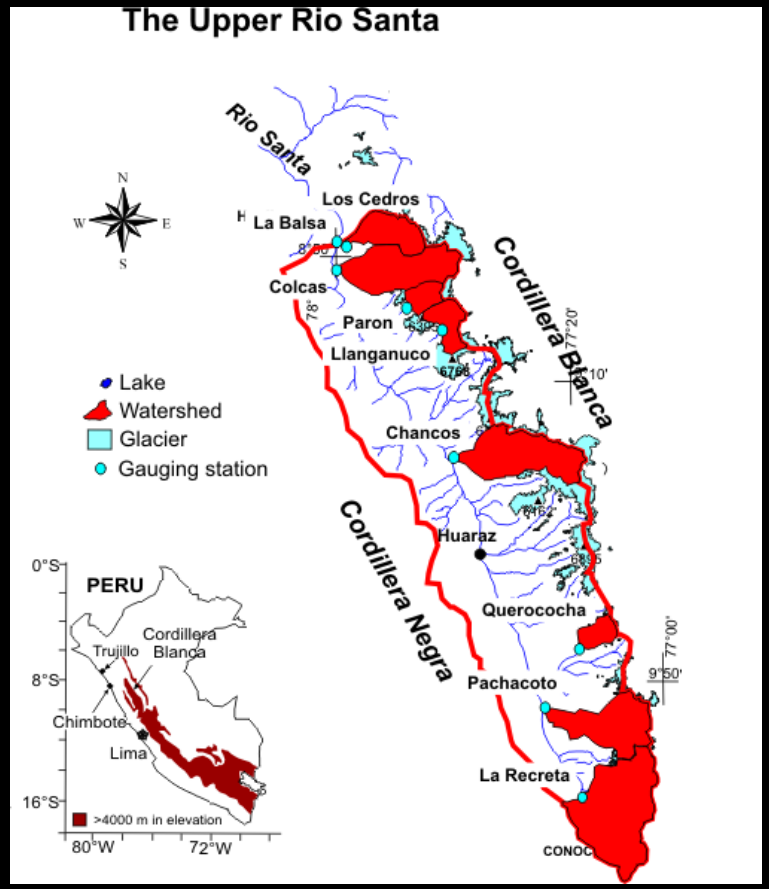
Baraer, et al., 2012. “Glacier recession and water resources in Perú’s Cordillera Blanca.” *Journal of Glaciology*, 58 (207).

Results in Cordillera Blanca

Peak water

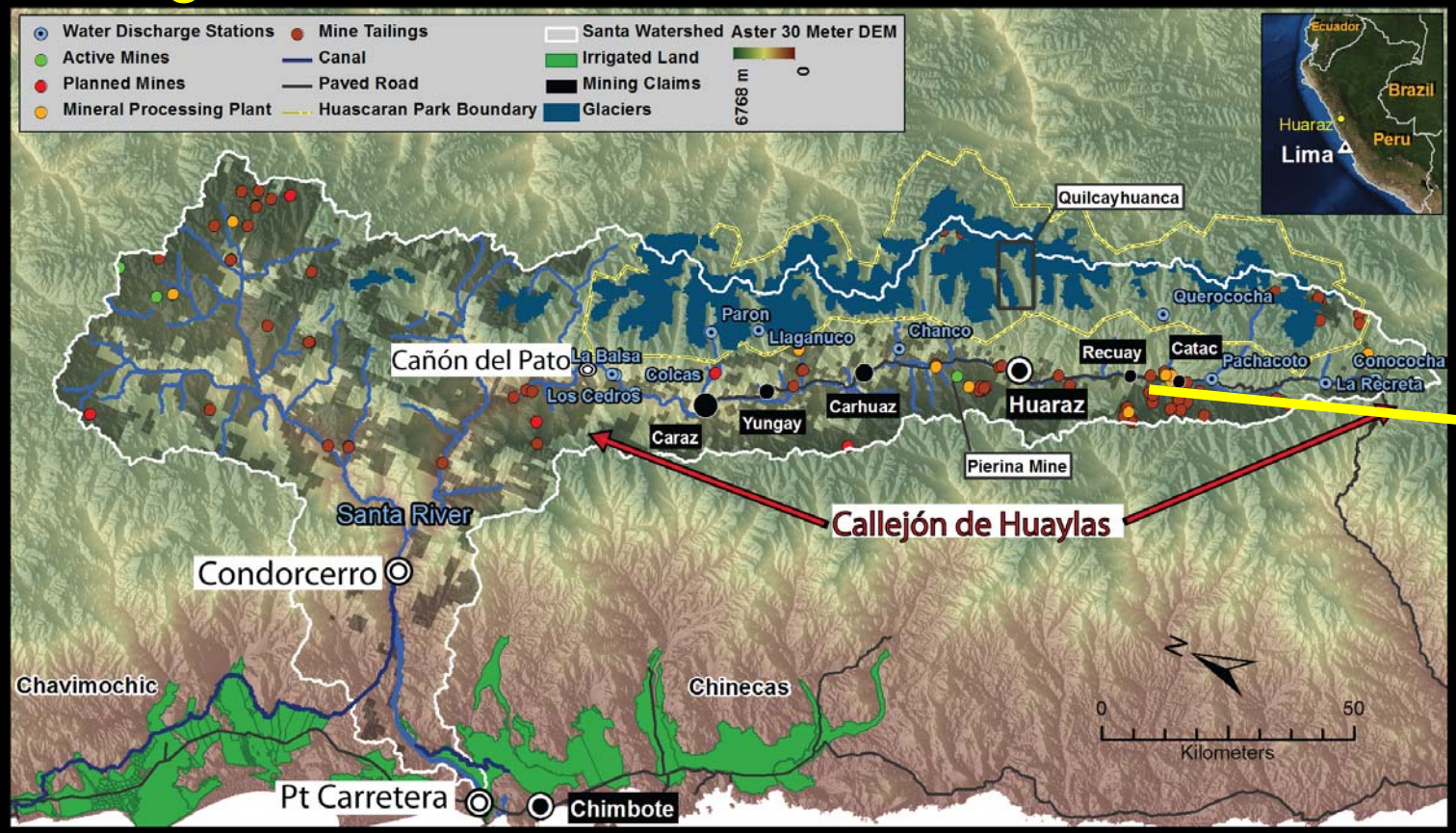


- Most tributaries to Rio Santa are past peak
- Current decline in dry season flow for upper Rio Santa (La Balsa) probably began in 1970s



Baraer, et al., 2012

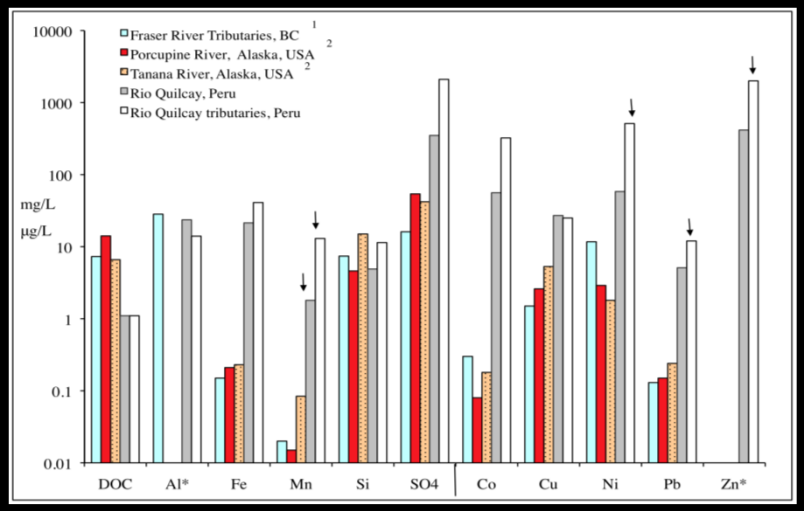
The Rio Santa water quality in a context of actual and past mining activities…

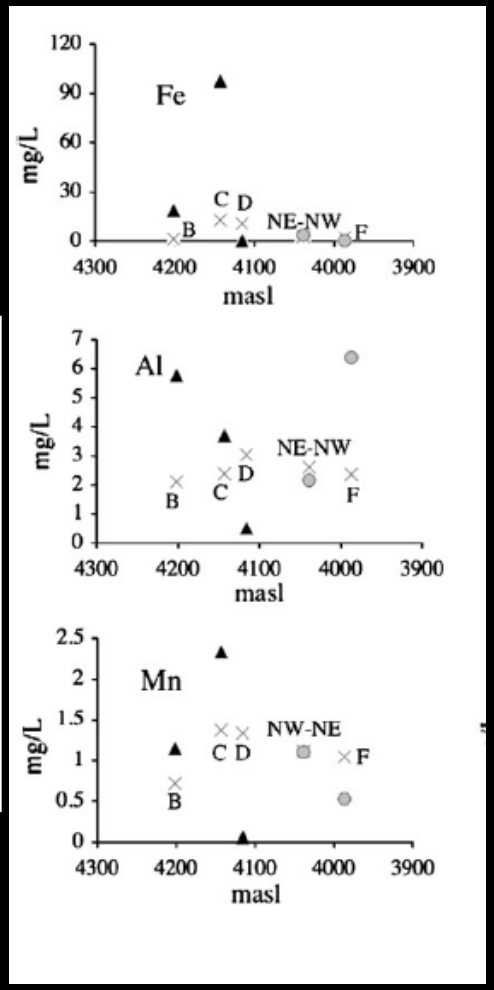


map by Jeff Bury, published in: Bury et al., 2013

...and natural contaminating deposits

- High concentration of heavy metals measured in some valley at elevations above human activities

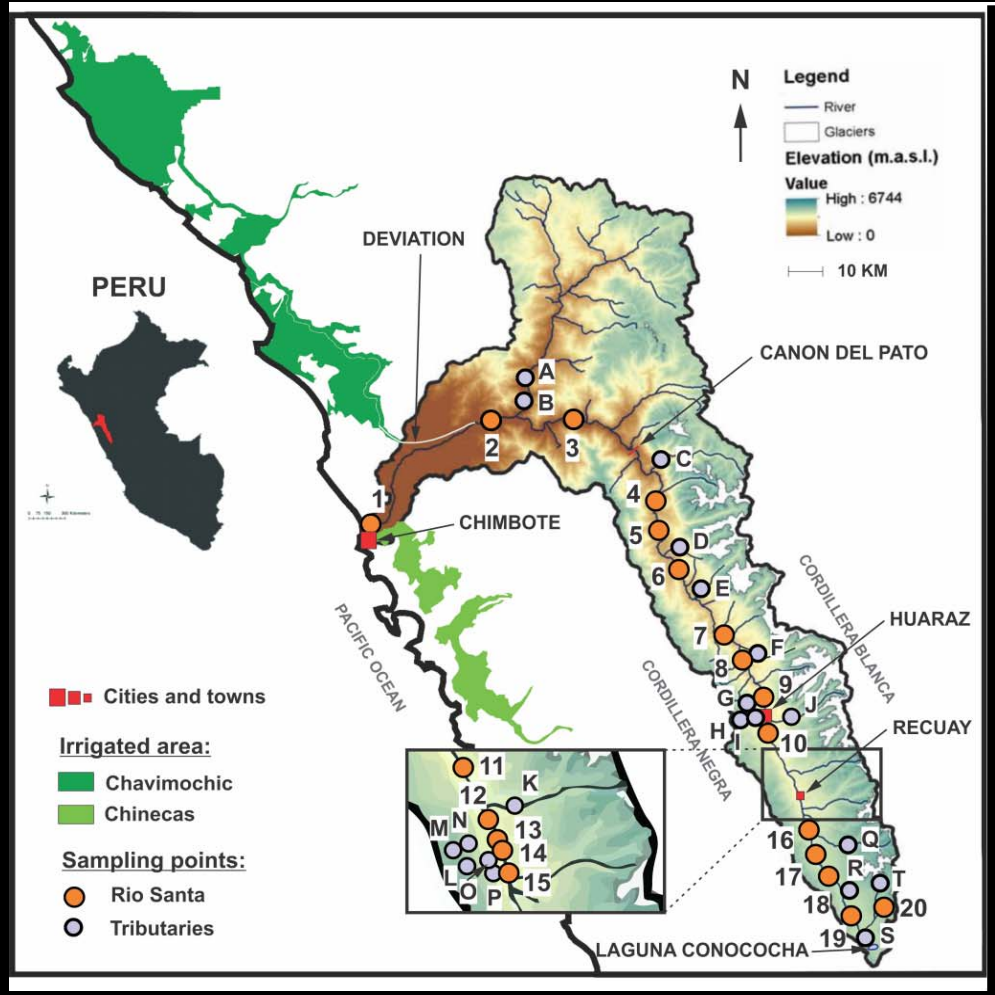




Data published in:
Fortner, Mark et al, 2011, *Elevated stream trace and minor element concentrations in the foreland of receding tropical glaciers.* Applied Geochemistry 26, 1792-1801.

2013 campaign

What is the extent, pattern (scale) & nature (process) of contamination?

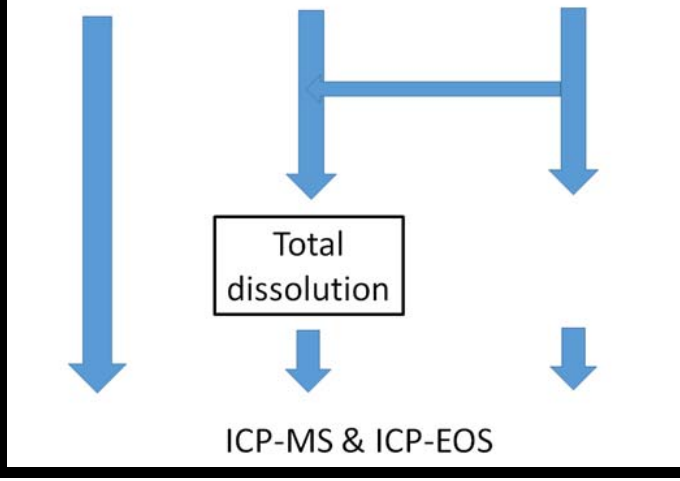


Sampling & analyses strategy:

- Full reach: Conococha to Pacific pour point; tributaries & main stem of Rio Santa
- Multi-sample: waters, suspended sediments & bed sediments
- Analytical focus: As, Cd, Pb, Al, Fe, Mn and Zn

Liquid, suspended sediments and river bed sediment sampling

Filtered water | Suspended solids | Sediments

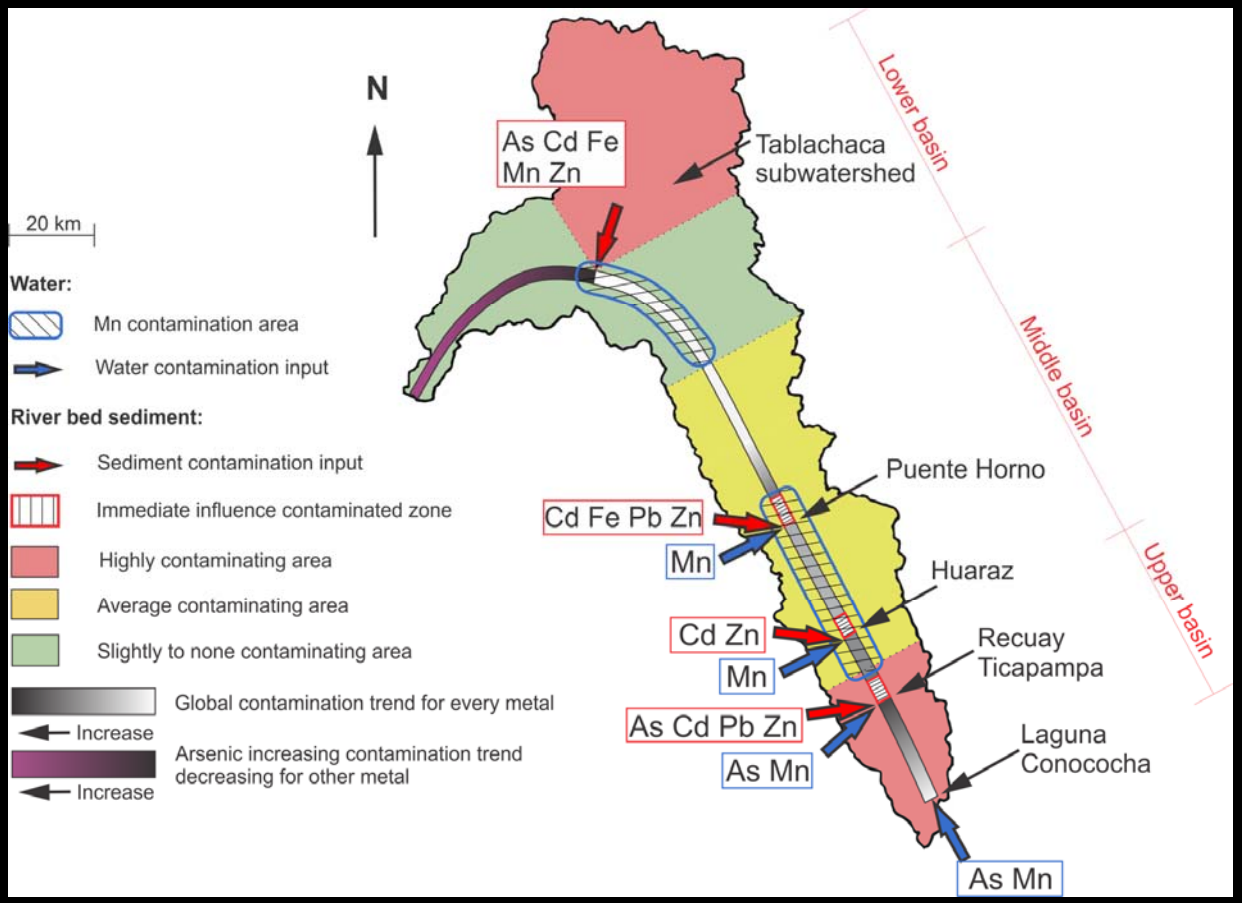


Contamination

- *Mn in water*
- *All elements in sediments*

Guittard et al., Trace metal contamination in the glacierized Rio Santa Watershed, Peru. In review, *Environmental Monitoring and Assessment.*

- The Rio Santa water is contaminated with Mn at more than 50% of the sampling points.
- Sediments collected in the Santa river bed were heavily contaminated by at least four of the tested elements at almost 85% of the sampled spots.



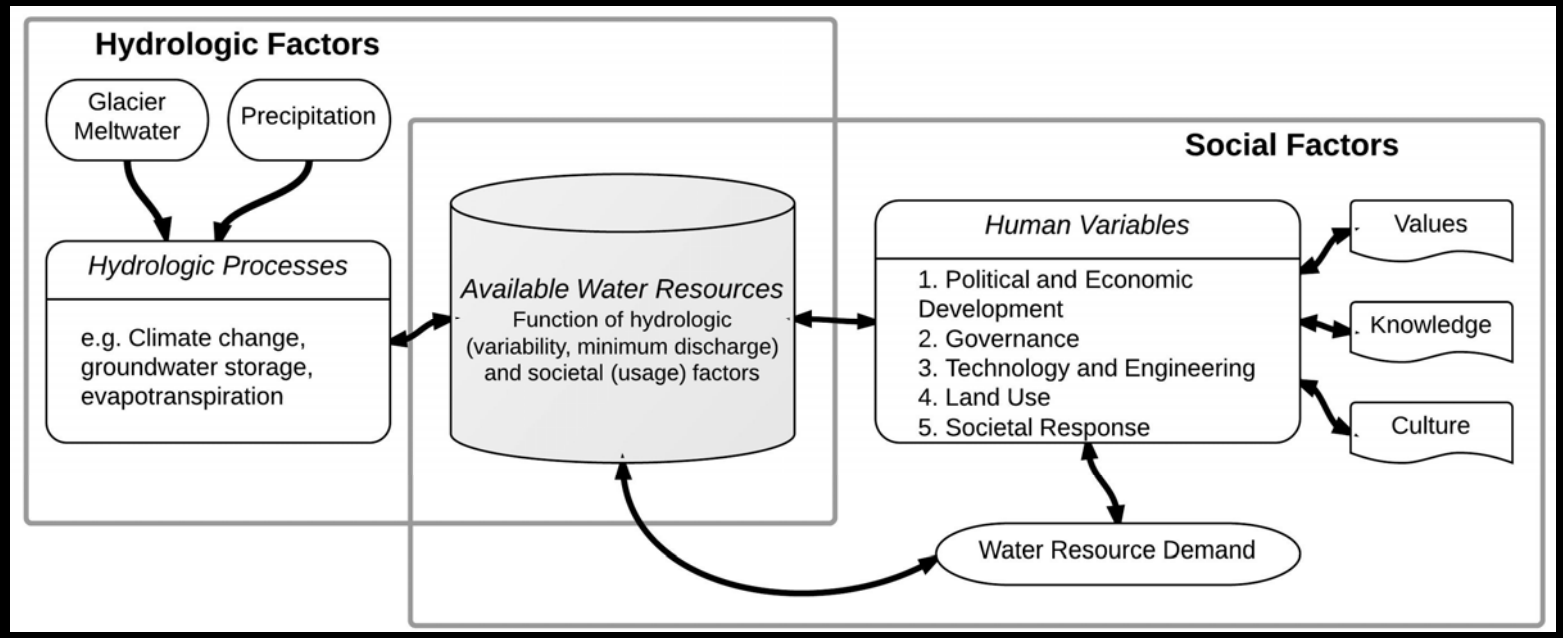
3) Coastal Chavimochic Irrigation Project

Year	Hectares Irrigated
1958	7,500
2004	144,000

map by Chavimochic

Availability ≠ supply

Demand is increasing



Flows are decreasing, more variable

Figure published in: Carey, et al., 2014, "Toward Hydro-Social Modeling: Merging Human Variables and the Social Sciences with Climate-Glacier Runoff Models (Santa River, Peru)," *Journal of Hydrology*: DOI: 10.1016/j.jhydrol.2013.11.006

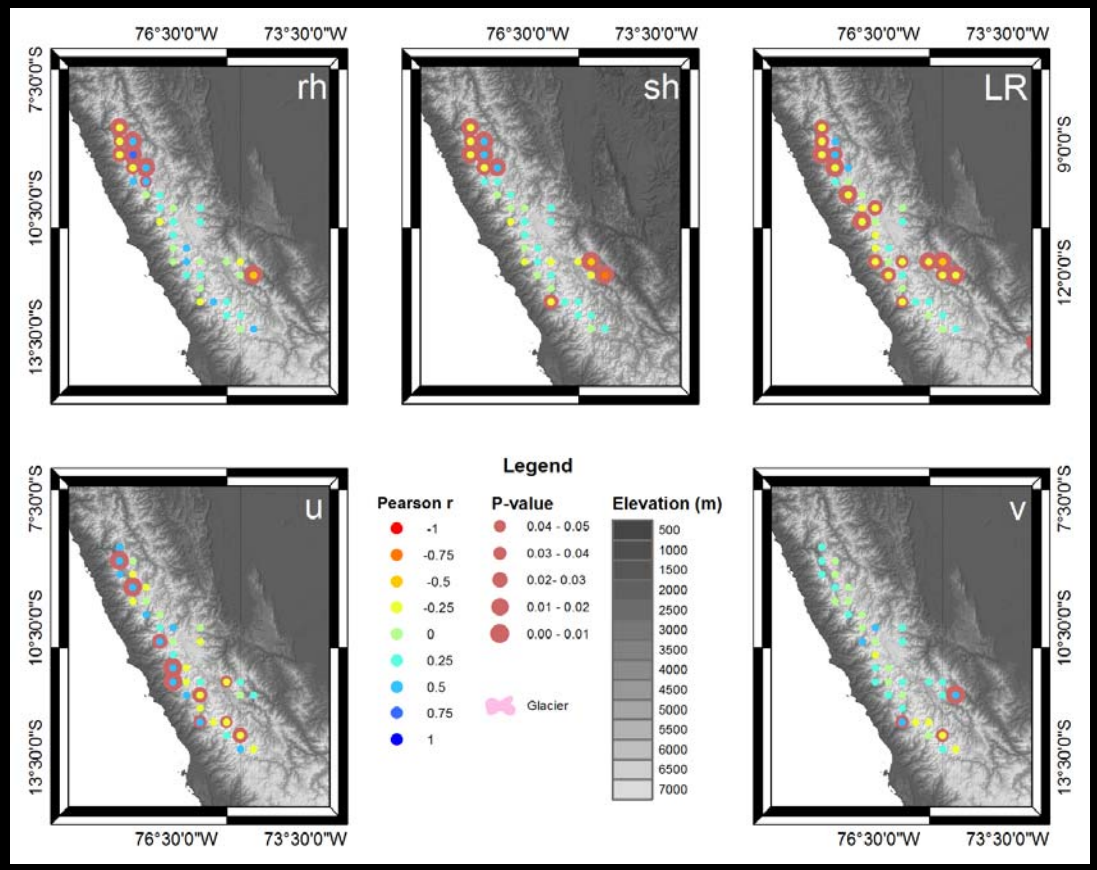
Global to regional climate change – impact to glacier mass balance (MB): *Can we explore causal factors with patterns in mass balance response?*

Pan-Andean (continental) MB modeling at 0.312° spatial resolution, forced with CFSR

MB model: sfc E balance, monthly

Statistical comparison using ERA reanalyses

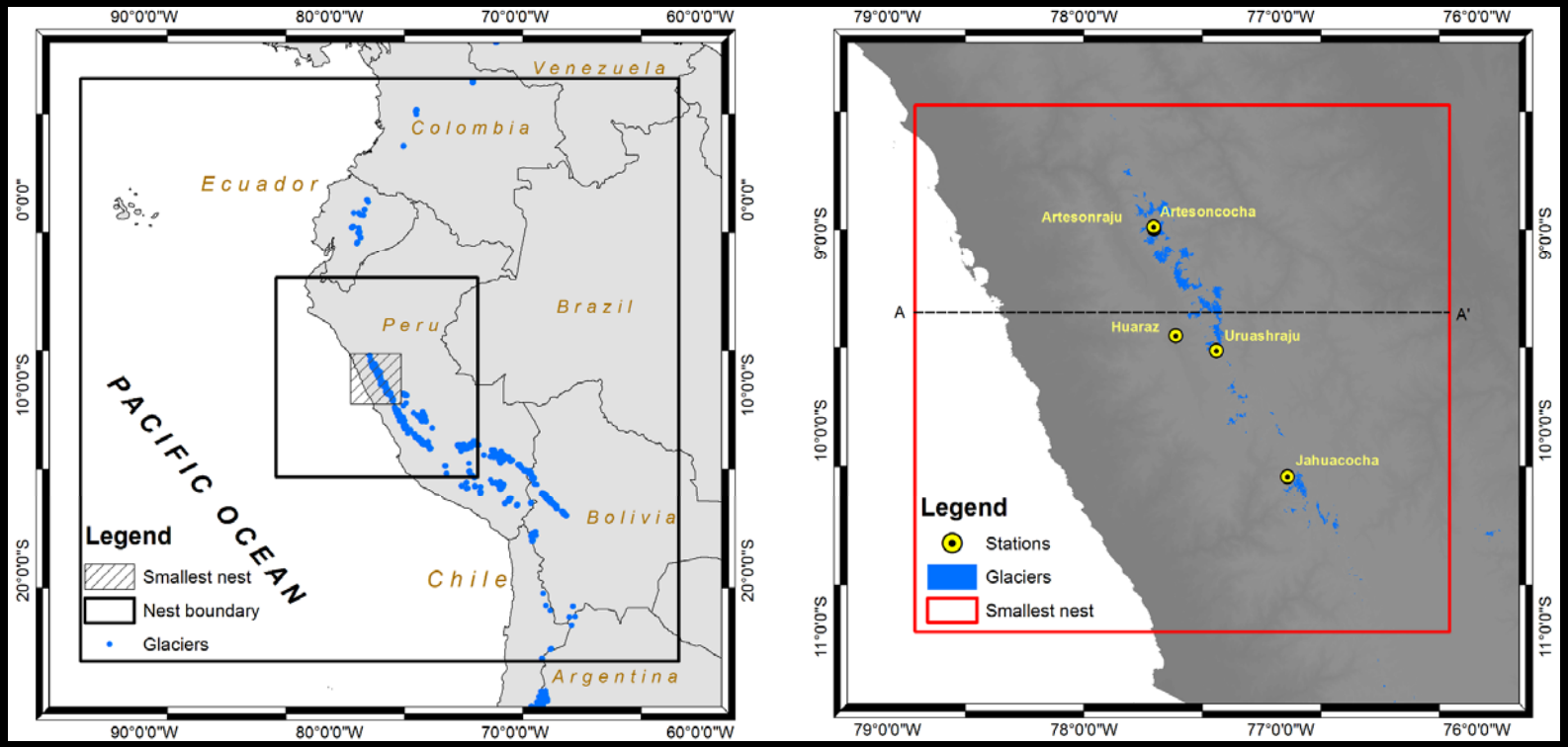
Temperature lapse rate (LR) significantly influences mass balance.



Fernandez et al., In prep

Dynamical downscaling over Cordillera Blanca: process understanding

E.g. What does it mean that lapse rate negatively correlates to mass balance?



Fernandez et al., In prep

Key insights

1. Rapidly melting glaciers redistribute water, but not uniformly
2. Streams are already past “peak water.” Groundwater is the major component of the dry season discharge
3. With altered glacier buffer in supply, there is less diluting effects of additional glacier water passing through the system; more water is coming from sources with more sediment/altered chemistry
4. Emergent vulnerabilities are variable, scale dependent and not constrained by physical hydrologic boundaries
   - Interlinked systems
   - Critical thresholds
5. Systematic understanding requires an integration of sustainable embedded observations, modeling and social science, with open sharing of data.

Mountain Research Initiative

Glaciers and mountain ecosystems, a new profile in Peru:
http://www.blogs-mri.org/?p=1234

FORO INTERNACIONAL DE GLACIARES Y ECOSISTEMAS DE MONTAÑA

10 al 13 AGOSTO 2016

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http://foroglaciares2016.pe/?lang=en

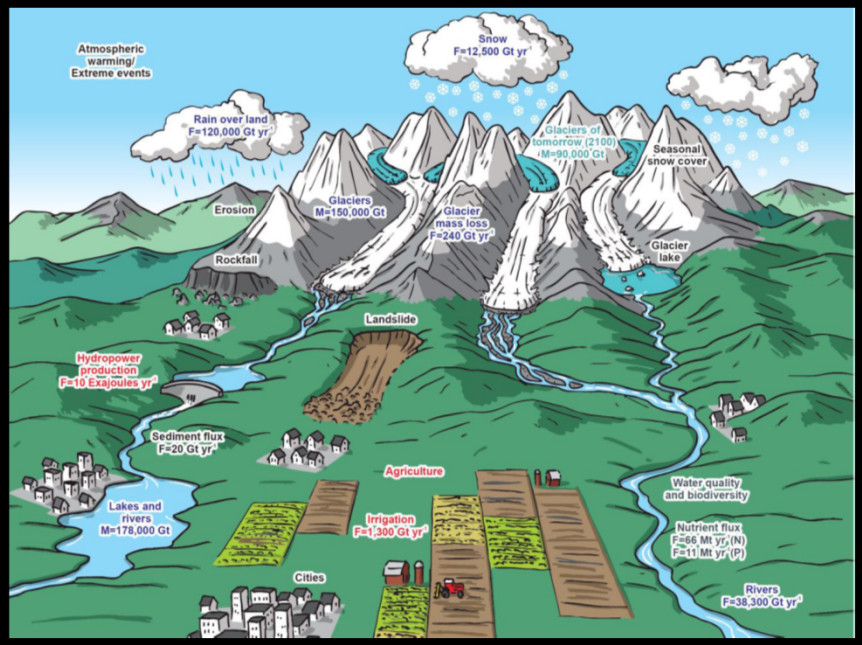

Fig from Huss et al., in review, *Future Earth: Mountains without permanent snow and ice*

Challenges & opportunities

- Partner relationships are difficult to foster, politically unstable, but important for observational continuity
- Data sharing and quality
- Integration & communication
- Understanding processes
- Heterogeneity & hyperbole
- Thresholds
- Scale matters

More at ESC meeting

Wed, June 15, POSTER 3:15-4:45 PM, Mershon Lobby:
#42. Oliver Wigmore *et al.*: UAV Mapping of Debris Covered Glacier Change, Llaca Glacier, Cordillera Blanca, Peru

Thurs, June 16, 8:50 AM, BPCRC (right here!):
Kyung In Huh (et al): Evaluating 50 years of tropical Peruvian glacier volume change from multi-temporal digital elevation models (DEMs) and glacier flow and hydrology in the Cordillera Blanca, Peru (Invited)

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http://bprc.osu.edu/glacierchange/

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A Century of Geography
Ohio State University

Bryan Mark
mark.9@osu.edu