Andean cryospheric observation from a transdisciplinary perspective

2016 Snow Watch, Ohio State, 14 June

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• Adam French (IIASA, Austria)
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• Pablo Lagos (Instituto Geofisico del Peru)
• Rolf Weingartner (Bern, OCCR)

Oliver Wigmore (PhD)
Gabriel Zeballos Castellon (PhD)
Andean cryosphere - changing climate

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

A. Fernandez, 2014, PhD thesis
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.
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
Lack of continuous observations

Data: WGMS
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

Georg Kaser, Martin Großhauser, and Ben Marzeion^1
Evaluating hydro-social vulnerability

Climate Change  Glacier Volume  Hydro Change  People

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 km²
Different water demands

Desert agricultural irrigation [webpage]

Chavimochic

Chinecas

Cañón del Pato hydroelectric plant
Photo: Mark Carey

Cordillera Blanca
Huascarán

Most glacierized tropical range
Rapid glacier recession

Trujillo

Yanamarey glacier

Mining

Agro pastoralism

40 km
Yanamarey glacier
2008 LiDAR Survey
Cordillera Blanca

Total area covered (564 km²). This represents 71 % of the total requested coverage of 792 km²

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

VOLUME changes (1962-2008)
Glacier change:

1. Volume loss 2-12 x > predicted

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


(1) Shifting seasonality of YAN discharge

Discharge (Q) and precipitation (P)

Area normalized (mm)

Glacier Headwaters

Photo: Oliver Wigmore, OSU
High resolution processes at glacier

(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


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=ERBBG4laoNo&list=PL85bdQbcuF0RU9XdB6T6Icnw-wE2wVK1A7&index=17
Livelihoods are natural resource dependent, diverse

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

Hydro transformation: Passing “peak water”

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:
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

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

- Mn in water
- All elements in sediments

- 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.

Guittard et al., Trace metal contamination in the glacierized Rio Santa Watershed, Peru. In review, Environmental Monitoring and Assessment.
3) Coastal Chavimochic Irrigation Project

<table>
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<tr>
<th>Year</th>
<th>Hectares Irrigated</th>
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<tr>
<td>1958</td>
<td>7,500</td>
</tr>
<tr>
<td>2004</td>
<td>144,000</td>
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map by Chavimochic
Availability ≠ supply

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

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

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