Modelling the glacier-hydrology of two large catchments in the Peruvian Andes

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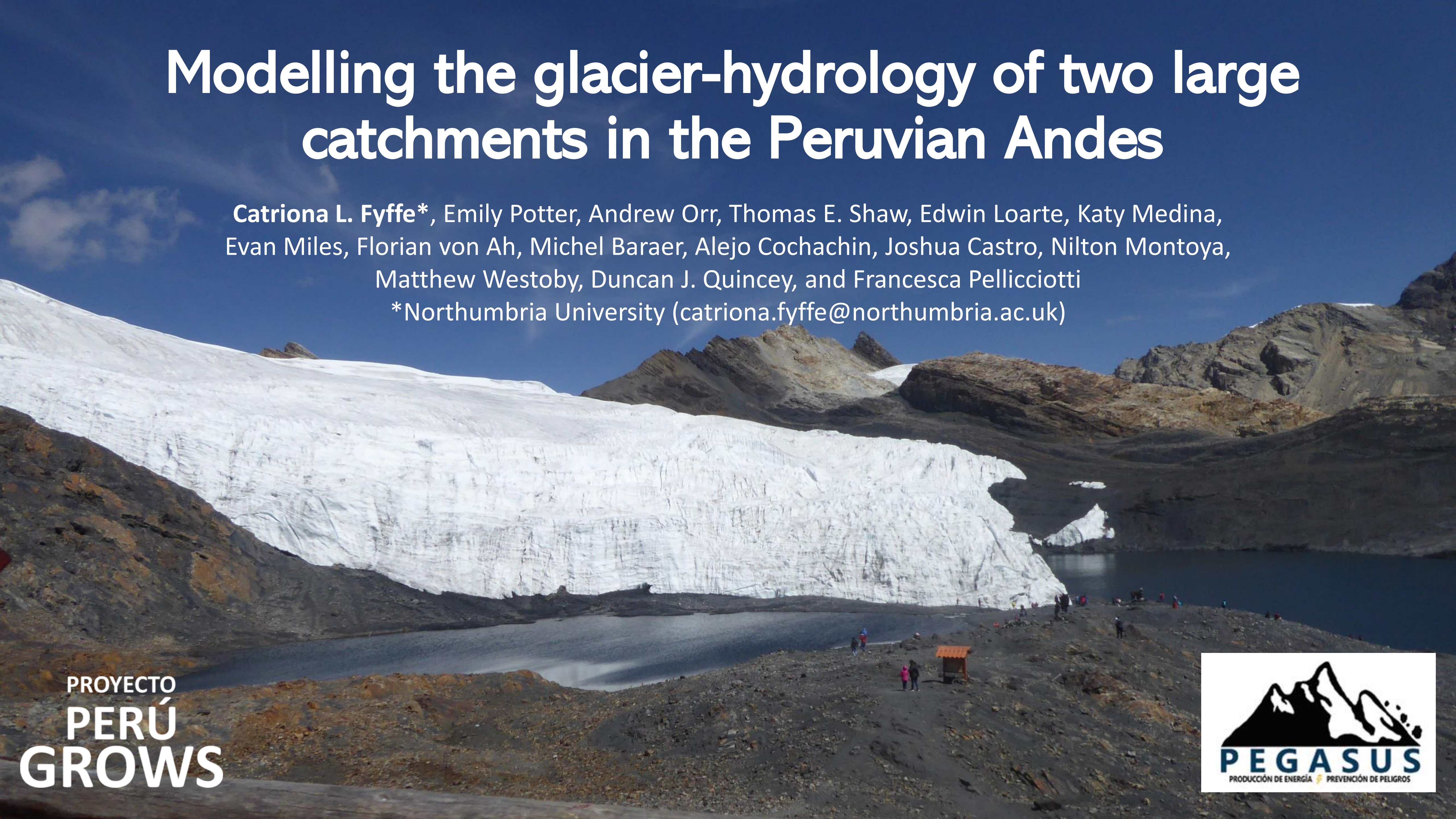


PROYECTO PERÚ GROWS

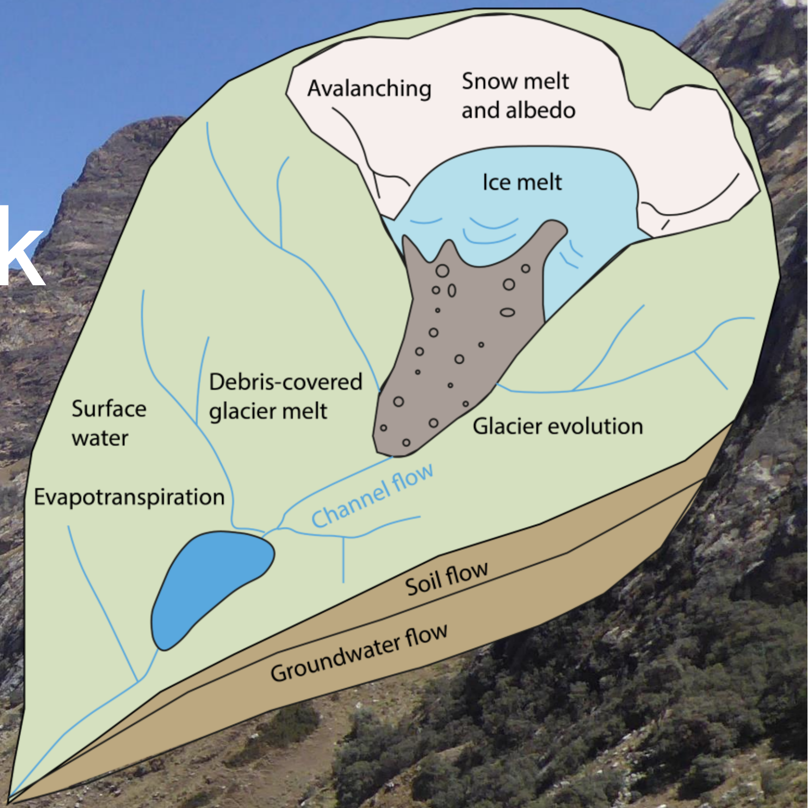
PEGASUS
PRODUCCIÓN DE ENERGÍA PREVENCIÓN DE PELIGROS

Rationale

- There is a strong seasonality in precipitation in Peru
- Glacier runoff is thought to be important for discharge (Mark and Seltzer, 2003; Mark et al., 2005) but these estimates involve simplifying the water balance and cannot differentiate between ice and snow contributions
- ‘Peak water’ is thought to have already passed (Baraer et al., 2012) but more physically-based modelling required to confirm this.

Local people rely on glacier runoff for agriculture, hydropower and consumption

Model framework



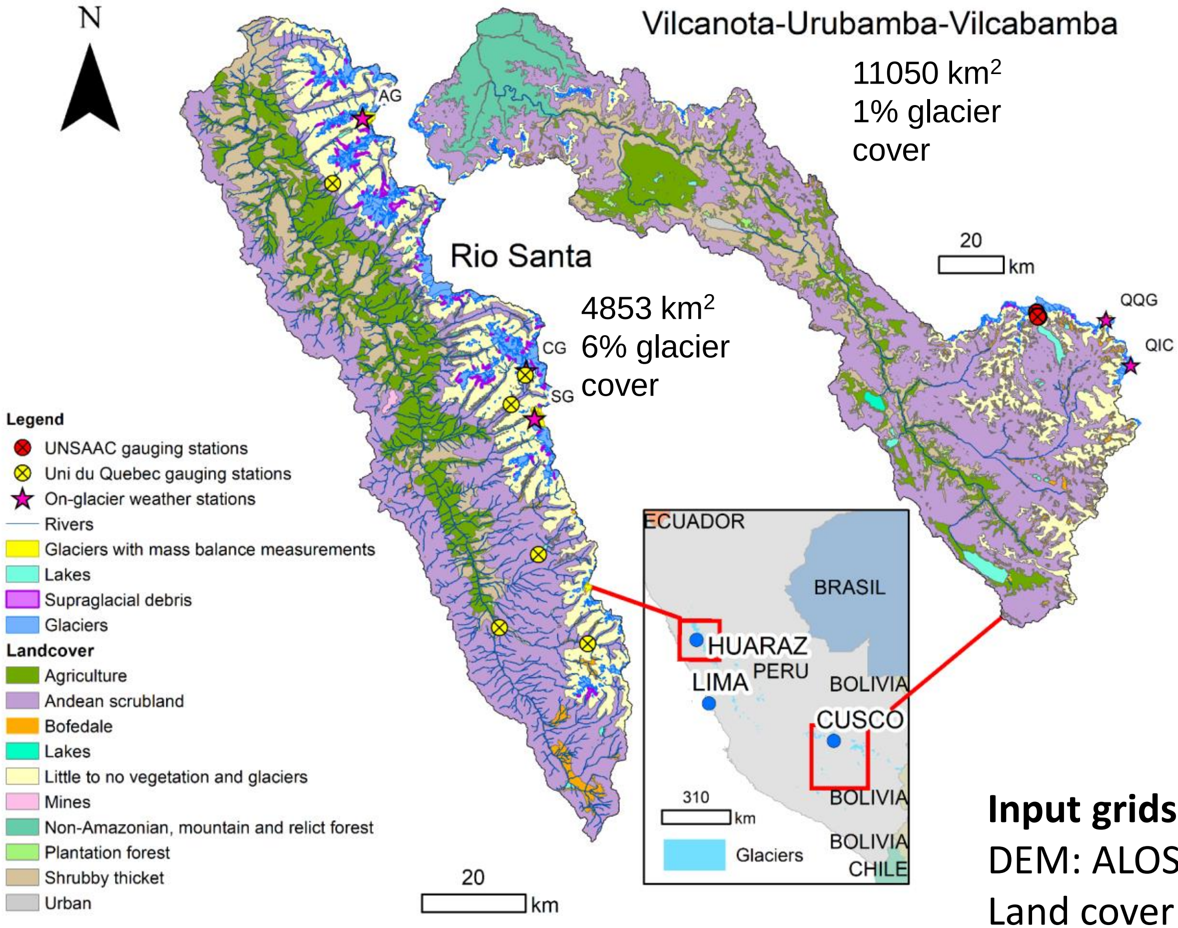
TOPKAPI-ETH

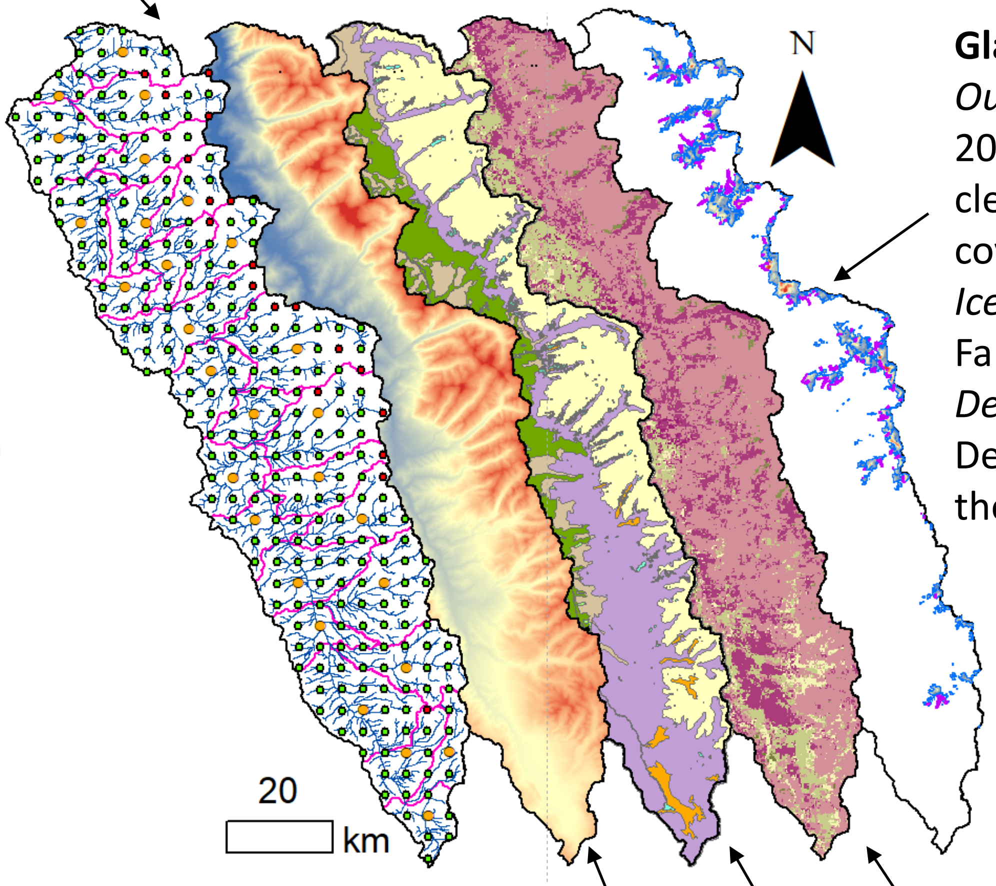
- TOPKAPI-ETH is an hourly physically-based, spatially distributed glacier-hydrological model
- Includes important glacier processes: clean and debris-covered glacier and snow melt (ETI), snow albedo decay, avalanching, glacier evolution and meltwater routing
- Simulates all the components of the water balance and transfers runoff through nonlinear reservoirs representing channel, overland flow, soil drainage and groundwater

Study sites and input data

Input meteorology:
WRF 4km hourly air temperature, precipitation and cloudiness. Bias-corrected against station observations.

Distributing input meteorology:
Ta: hourly average lapse rates per subcatchment
Pr: monthly average lapse rates per subcatchment
Cloudiness: directly from each 4km cell





Glaciers:
Outlines: INAIGEM 2018 inventory for clean and debris-covered glaciers
Ice thickness: Farinotti et al. (2019)
Debris thickness: Derived from thermal imagery

Input grids: 100 x 100 m cell size.
DEM: ALOS PALSAR (Rio Santa) or AGDEM (Vilcanota)
Land cover: Mapa Nacional de Cobertura Vegetal (MINAM)
Soils: World Reference Base soil types and depth to bedrock from SoilGrids.

Calibration

Precipitation phase threshold

- Find air temperature threshold which allows amount of solid and liquid Pr to match Ding et al. (2014) method.

Melt

- Pellicciotti et al. (2005) enhanced temperature index (ETI) model.
- Energy balance melt modelled at five sites across both catchments (Fyffe et al., 2021) compared to ETI melt.

Albedo

- Brock et al. (2000) deep snow equation.
- Parameters calibrated against measured albedo at a site in each catchment.

Air temperature over glaciers

- Found air temperature decrease required to minimise difference in melt between the TOPKAPI melt and the energy balance model

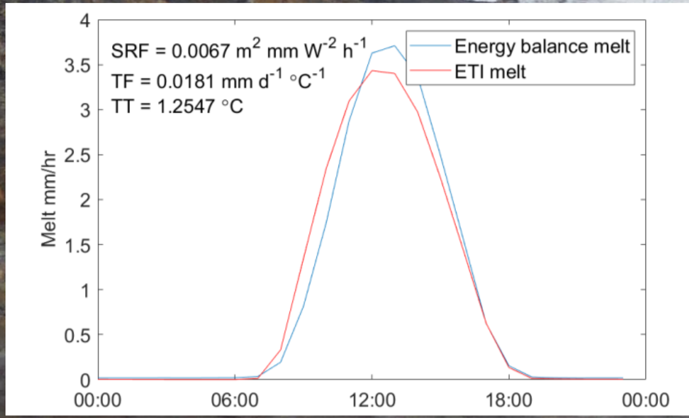
Glacier reservoir parameters

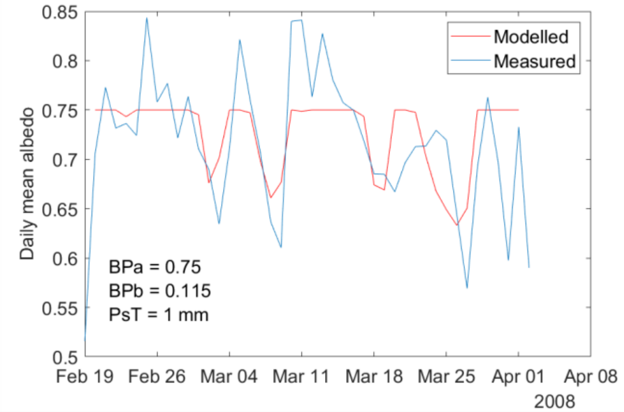
- Linear reservoirs used to route snow and ice melt.
- Calibrated against measured discharge from Cuchillacocha Glacier.

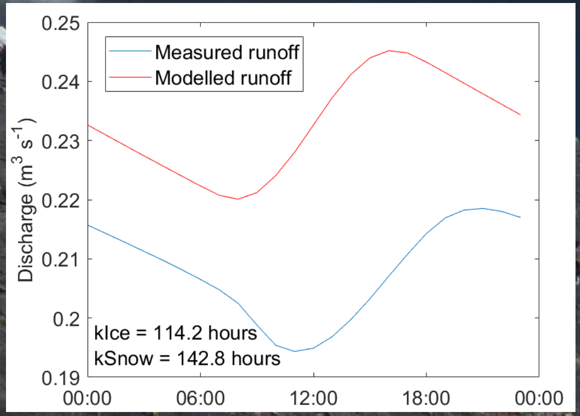
$$M = \begin{cases} \mathrm{TF}\,T + \mathrm{SRF}(1-\alpha)G & T > T_\mathrm{T} \\ 0 & T \leq T_\mathrm{T} \end{cases}$$

$$\alpha = BPa - BPb\,log_{10}T_a$$

$$Q^t = Q^{t-\Delta t}\exp\left(-\frac{\Delta t}{k}\right) + \left(1-\exp\left(-\frac{\Delta t}{k}\right)\right)Q_{In}^{\Delta t},$$

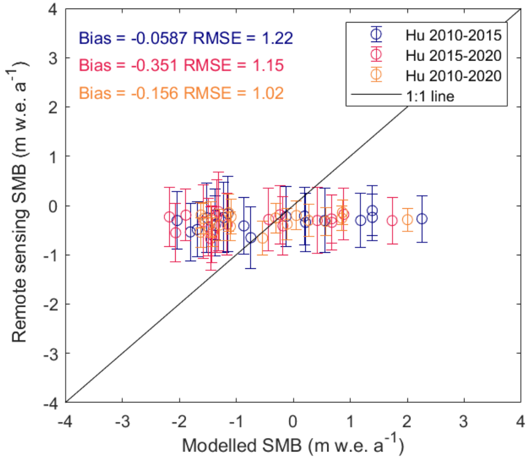


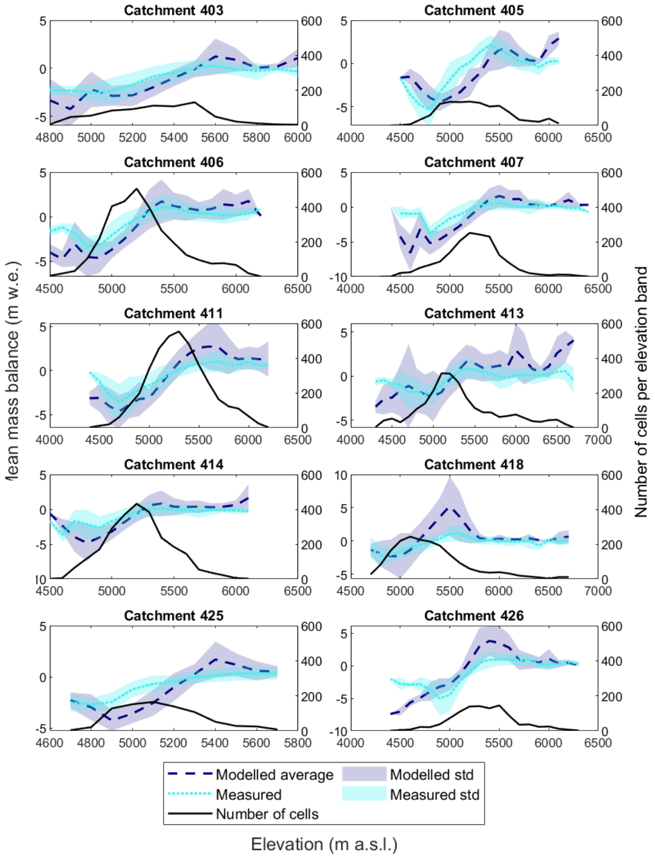




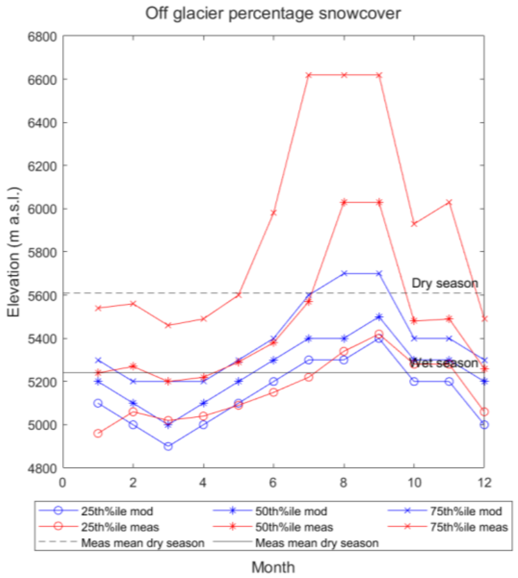
Validation 10 year TOPKAPI run 2008-2018, with 3 year spin-up

Glacier mass balance: Altitudinally resolved glacier mass balance (following Miles et al., 2021). Glacier average mass balances from Hugonnet et al. (2021) (both) and Taylor et al. (2022) (Vilcanota)

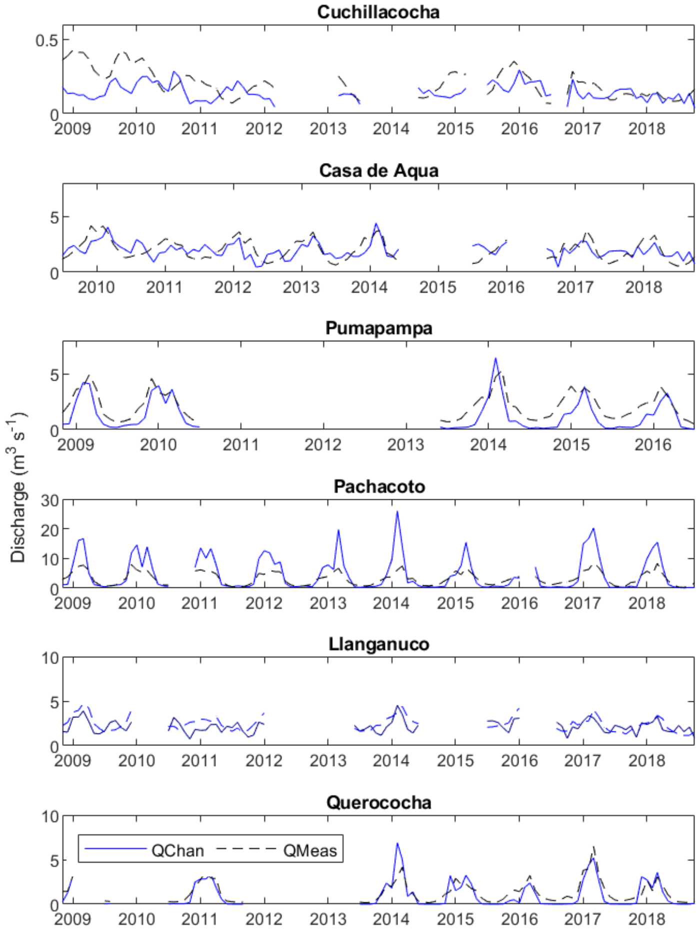




Off-glacier snowline elevation: Average monthly snow frequency maps derived from Landsat and Sentinel-2.

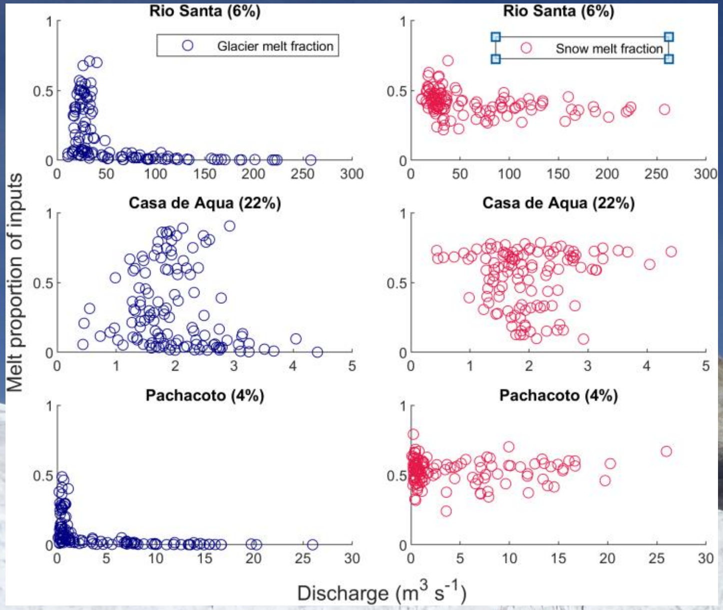


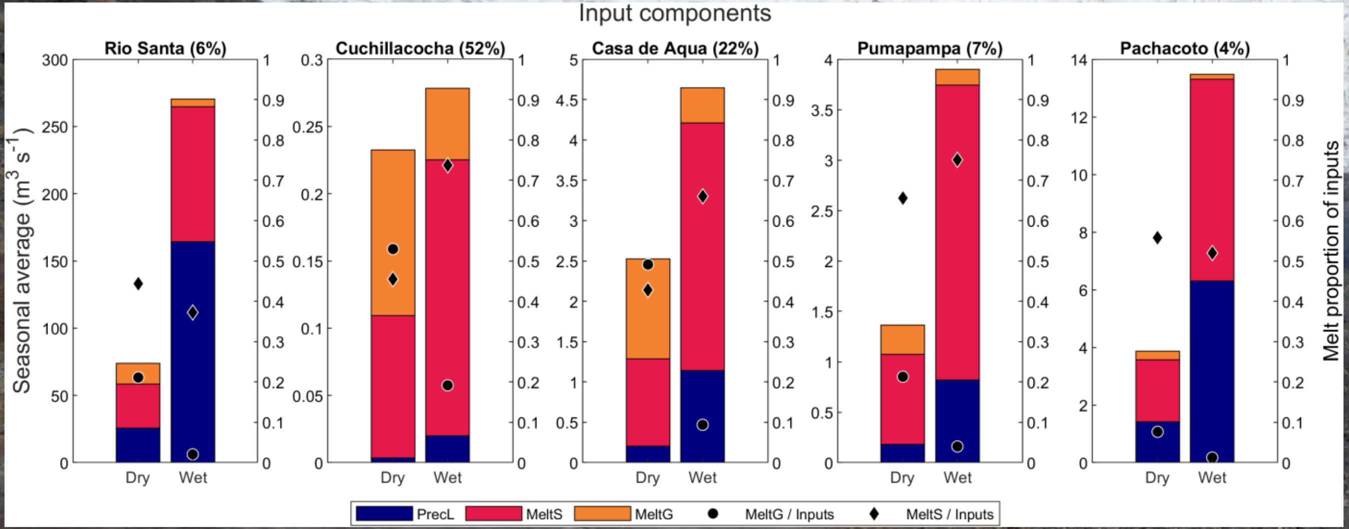
Measured discharge: Six stations within the Rio Santa catchment (Mateo et al., 2021)

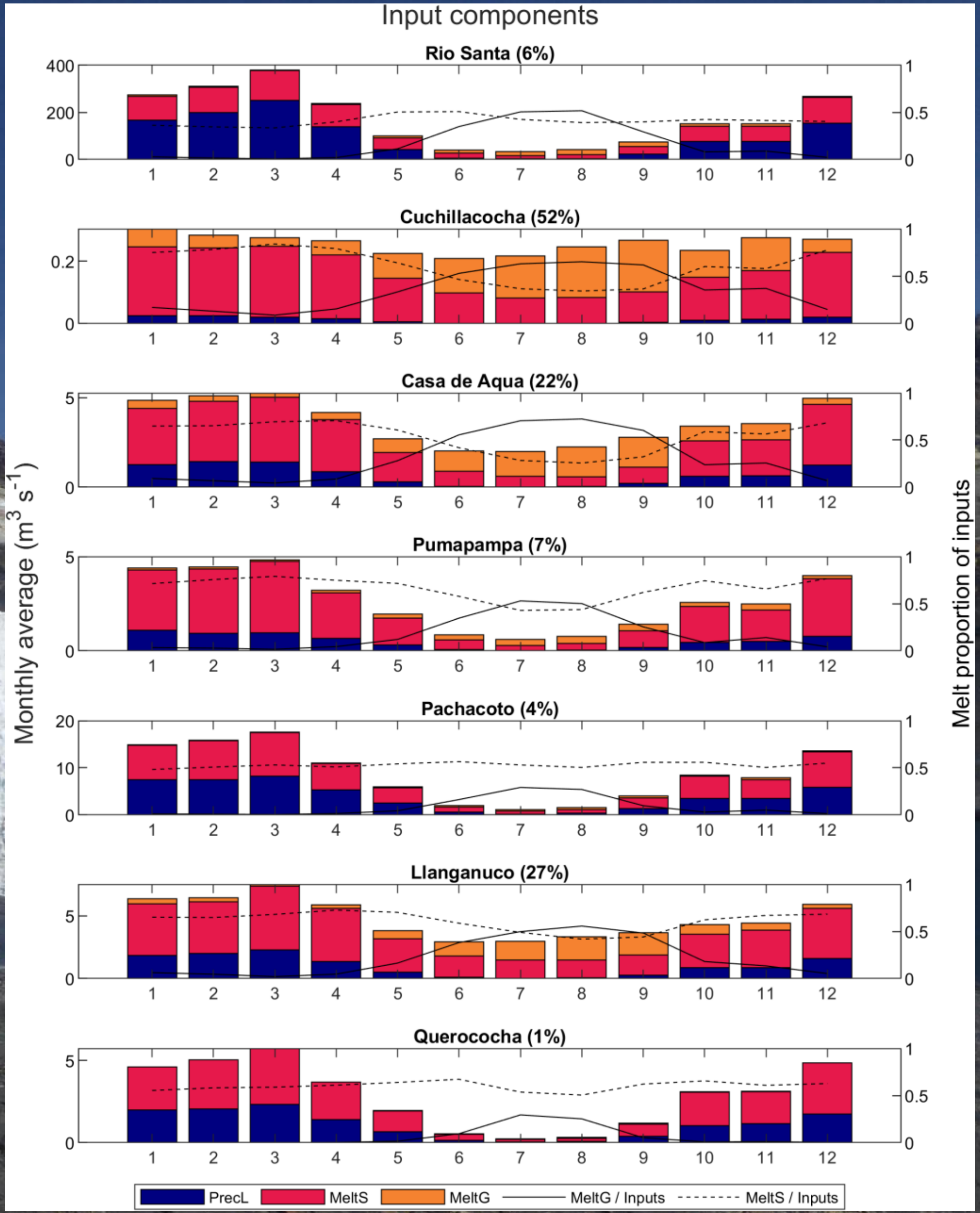


Results: Importance of melt

- Strikingly snow melt is a significant source of inputs to runoff all year, being min. 34% of inputs to the Rio Santa.
- Ice melt is most important in Aug and least in Dec (52% c/f 2% in the Rio Santa)
- Even in low glacier cover catchments, glacier melt is important : it comprises 29% of July inputs in Querococha.





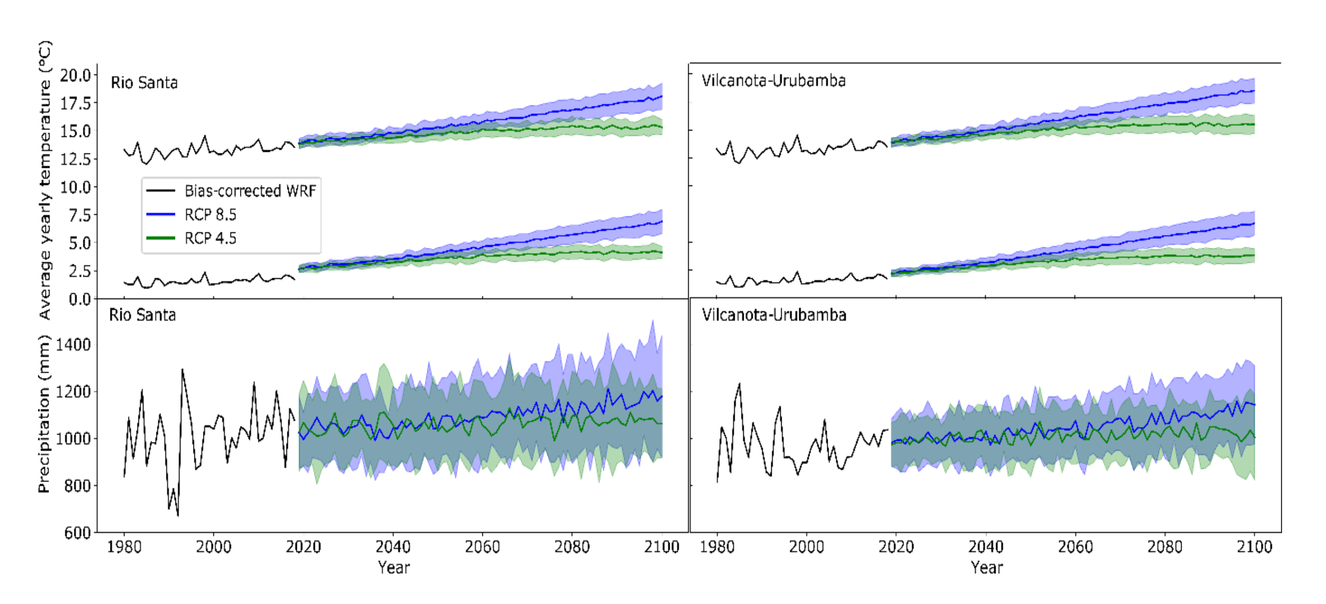


Conclusions

- A multi-step calibration strategy using a variety of ground and remotely sensed data allows parameters to be calibrated separately, reducing equifinality and the need to calibrate solely against discharge
- Our modelling allows the differentiation in the importance of snow and ice melt to catchment runoff: snowmelt is important all year, whereas glacier melt is most important in the late dry season, even in catchments with a small glacier cover

Outlook

- WRF climate data is available as a hindcast 1980-2018. TOPKAPI will be run using this hindcast to check the glacier evolution and determine the existence and timing of 'peak water'.
- Climate projections are also available to 2100 based on both statistical and dynamical downscaling of global climate models, these will be used to force the model into the future and predict glacier and runoff evolution



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Potter et al. (in prep.)

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