Influence of evaporation on glaciated basins water budget: a case study in the Cordillera Blanca, Peru

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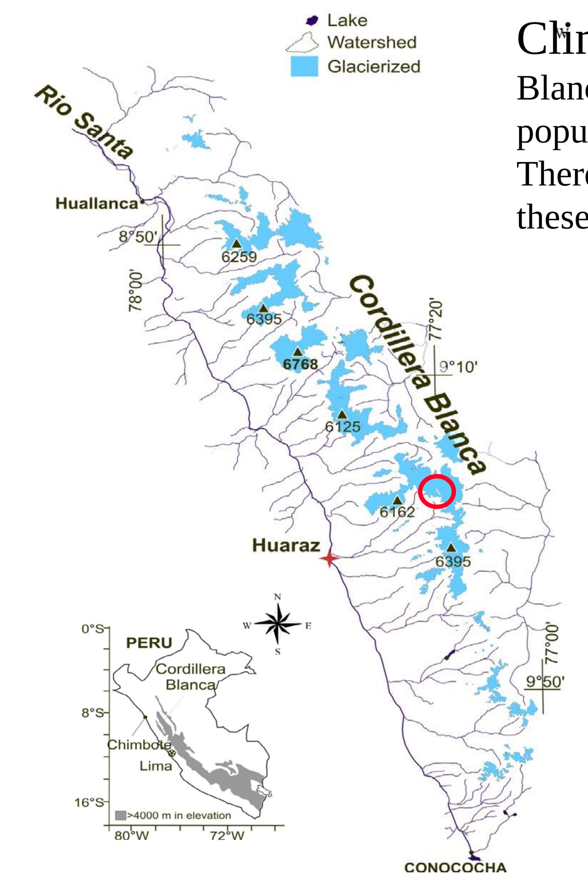
1- Context of the study

The Cordillera Blanca. Situated in Northern Peru, the Cordillera Blanca has the largest concentration of glaciers in the tropics. The mountain range covers a south-north distance of about 120 km. Glacial melt water contributes to around 30% of dry season discharge of the upper Rio Santa, the river that drains its western side (Baraer et al., 2012).



Peru and Cordillera Blanca maps. The Cuchilla Lake position is circled in red

Climate changes impacts. The ongoing retreat of the Cordillera Blanca glaciers impacts the hydrological budget, and down-stream populations, ecosystems and economy (Mark and Seltzer, 2003). Therefore, it is important to understand glaciers at the head-waters of these systems.

Research objectives. Previous studies of Cuchilla Lake (4625 masl) showed that the daily peak discharge at the lake outlet has a 12 hours lag compared to what is generally observed at glacier fed lakes. The objective of this study is to identify what phenomenon drives this atypical behavior.

Cuchilla Lake catchment

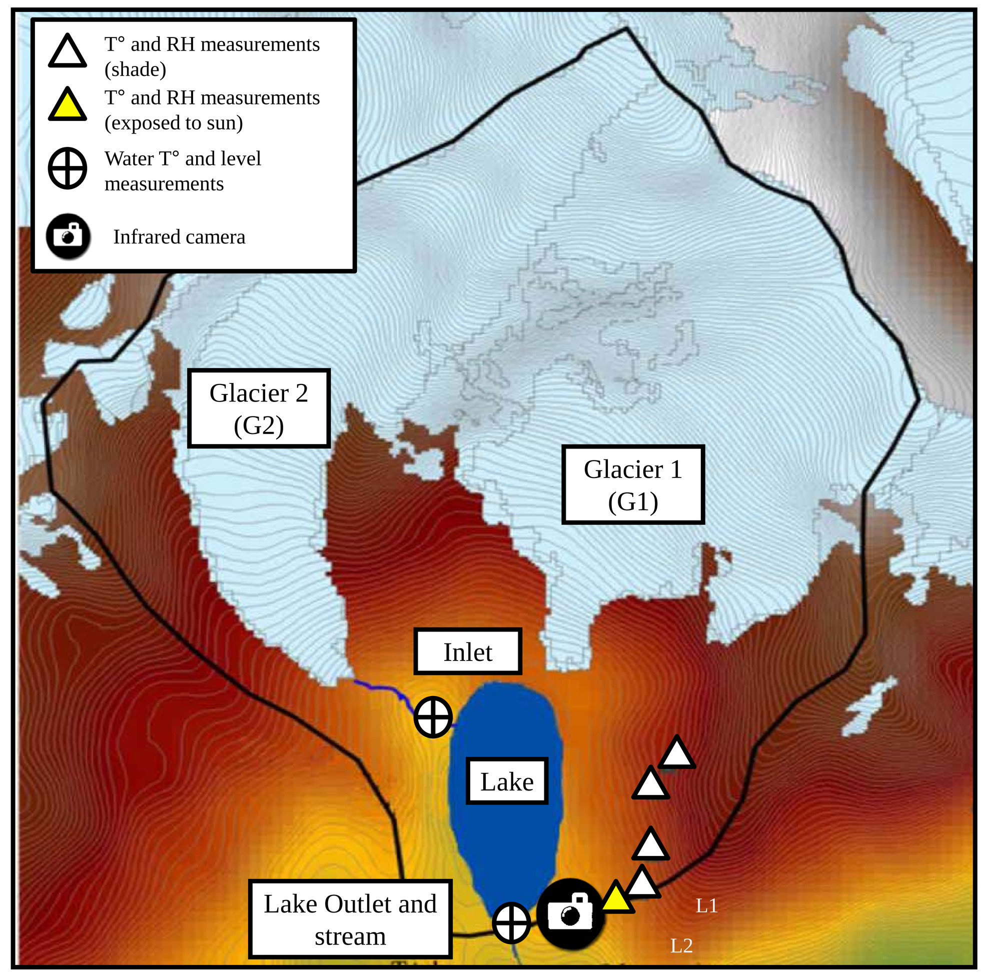
2- Field Data

Data collection. The data used in this study was collected over a 24 hour period, starting 11:30 on July 20th, 2011.

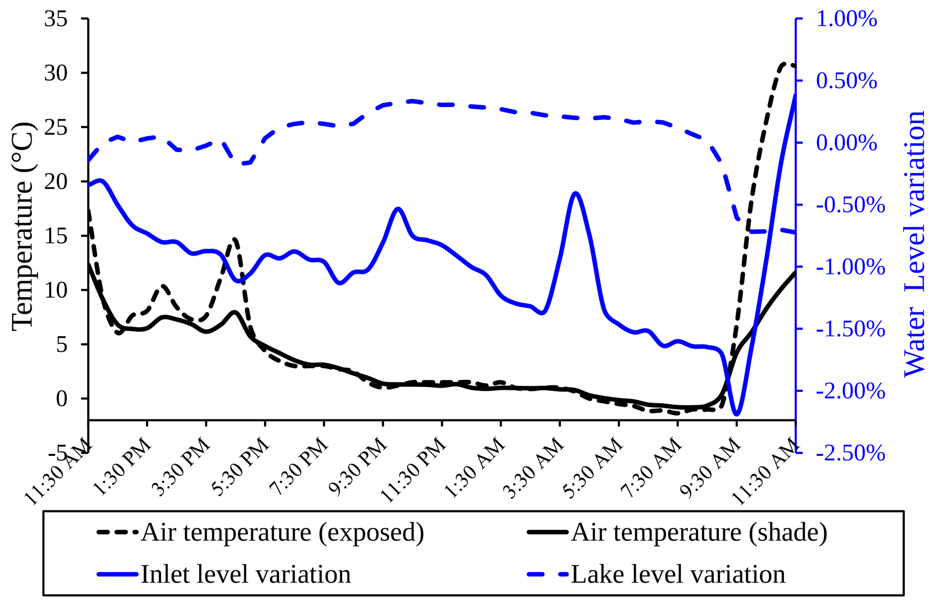
Air temperature was measured at five locations (L1 to L5). L1-L4 were used for temperature average and L5 was used for an approximation of insolation, as it was placed in the sun and had strong variability.

The variation in the lake level , in the inflow stream level and the water temperature were measured both at a lake inlet and at its outlet

Infrared pictures were taken every 30 minutes with an interruption between 10 PM and 4h30 AM due to bad weather conditions



Cuchilla Lake and the field data collection site



Observations. We observe that, from 8:30AM to 11:30AM, as insolation and temperature rise, the stream height increases and the height of the lake decreases. One explanation could be that the influx of water from the stream is smaller than the evaporation at the lake surface during this period.

Also, the inverse correlation between the lake height and the insolation, representing the energy influx to the lake, reinforce the idea that evaporation is a driving process. This can be seen at 4:30PM, where an increase in insolation decreases the height of the lake

3- Estimation of the lake evaporation

To assess if lake evaporation is high enough to explain the atypical water balance, the potential evaporation rate was calculated using 3 models: Abtew, Makking and Hargreaves. Radiation measurements were derived from two nearby glaciers.

Equation and parameters of the evaporation model

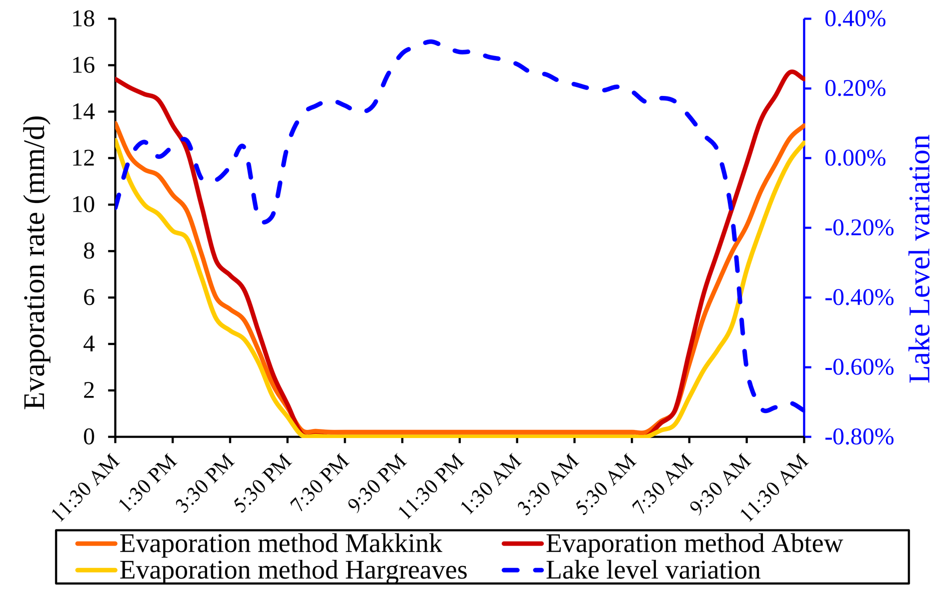
Model	Evaporation rate equation	a (1/°C)	b (°C)
Abtew	$a (R_{ns}/\rho\lambda)$	0.53	
Makkink	$a (\Delta/\Delta+\gamma)(R_{ns}/\rho\lambda) + b$	0.77	2.31x10-9
Hargreaves	$a (T_a+b) R_{ns}/\rho\lambda$	**0.0145**	**17.8**

Symbol	Parameter
R_{ns}	Shortwave radiation (W/m2)
ρ	Density of water (kg/m3)
λ	Latent heat of vaporization (J/kg)
Δ	Var. of the saturation water pressure with T (Pa/°C)
T_a	Air temperature (°C)

The equations used are based on Delclaux, 2007.The parameters in bold were recalibrated by Xu and Singh (2000).

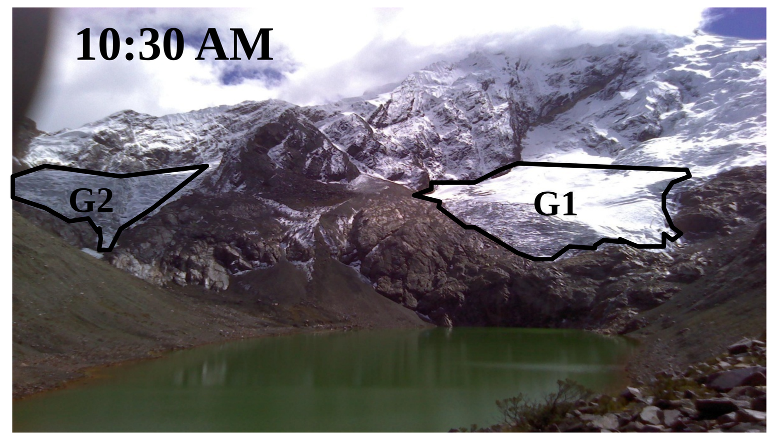
Results. The evaporation estimations are coherent even if they were calculated using different models.

This reinforces the hypothesis that evaporation is a major driver of the lake budget. Evaporation of the water at the surface of the lake might explain the disparity in lake level and inlet level.

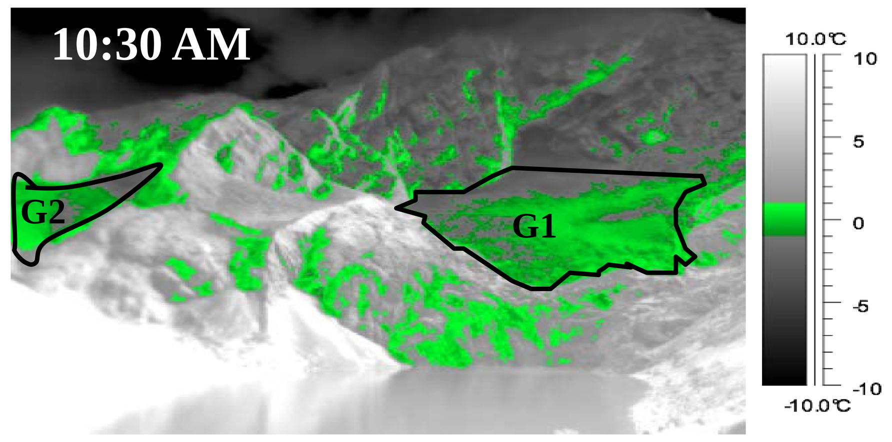


4.Evaluation of glacial melt

Infrared image analysis of glacial melt. Infrared pictures were used to calculate the percentage of the observed glacier surface that was melting. For that purpose, a melting area was defined as being a glacier area which surface temperature situates between -0.5 and 0.5 °C. These areas are higligted in green on the infrared pictures.



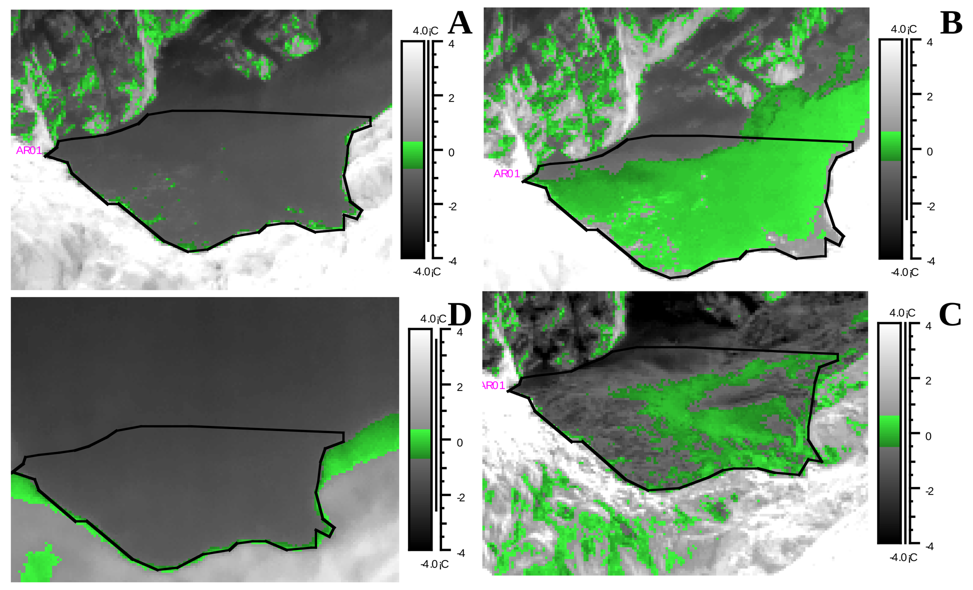
Digital picture

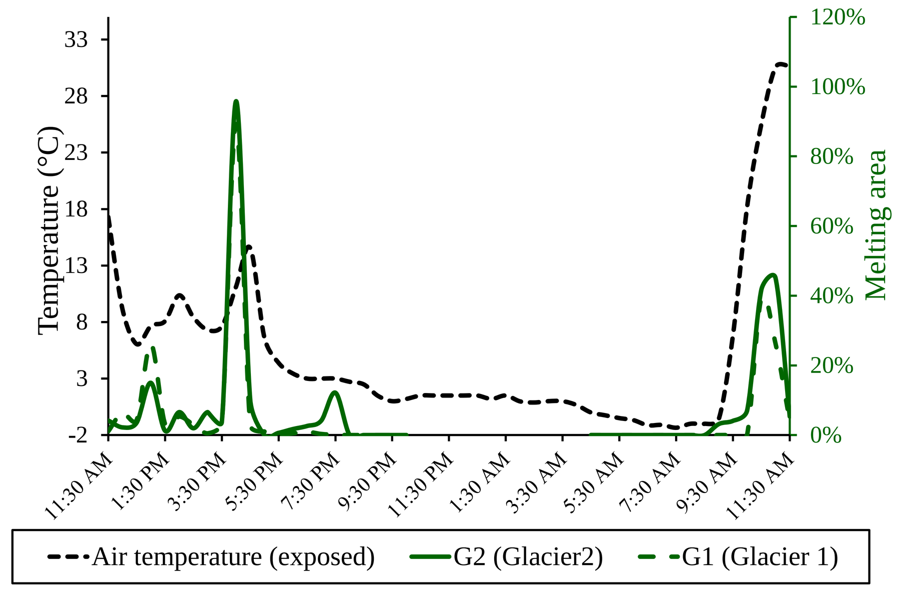


Infrared picture

Evolution of the glacier 1 melting surface

A. 2:00 PM, The contours of the glacier mainly are melting.
B. 4:00 PM, Melt maximum observed under clear sky.
D. 4:30 PM. Cloud cover impairing accurate measurement.
C. 10:30 AM on July 20th, limited melting area.





Melting area. Each infrared image was analysed to find the relative melting area for G1 and G2. The results show that the glacier's melt area is closely related to insolation. With cloudy weather, insolation is low and the relative melt of the glacier is near zero. When the sun comes out, insolation peaks, resulting in a peak in relative melt

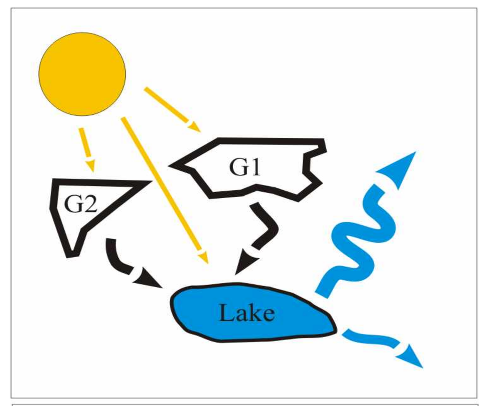
5. Discussion

Water balance models. Based on the results, we propose a water balance model for three times of the day: 4:00 PM, when the lake level does not show a strong anomaly; 09h00 PM, when the lake level gets close to its maximum and 9:30 AM, when the disparity between the inflow stream level and the lake level is largest.

The size of the arrows represents the relative amount of water in the transfers. G1 and G2 represent each sections of the glacier. The lake level is taken in relation to the lake level at 11:30AM on July 20th. Other elements of the water balance have been ignored for the model.

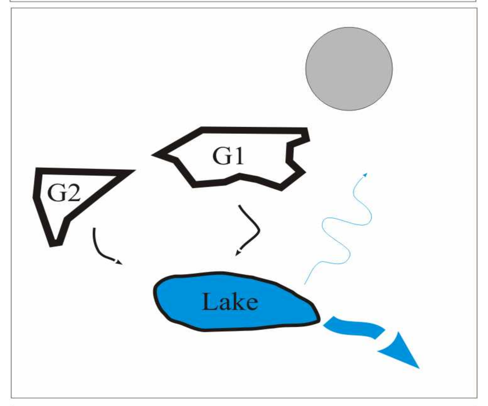
Water Balance at 4:00 PM

- High glacier melt means a high influx of water
- High evaporation rate means a lowering of the lake
- This results in a medium lake outflow



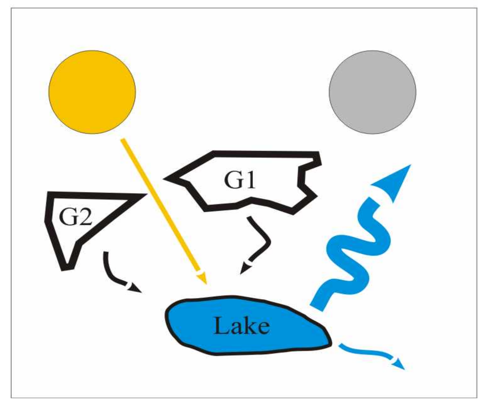
Water Balance at 9:00 PM

- Minimal glacier melt means a low influx of water
- Low evaporation rate means an high lake level
- This resulting in a high lake outflow



Water Balance at 9:30 AM

- Low glacier melt means a low influx of water
- High evaporation rate means a lowering of the lake
- This resulting in a lower lake outflow.



Proposed next steps. The accuracy of this research could be increased by:

- 48 hours of field data instead of 24
- Obtaining radiation measurements from the Cuchilla Lake area
- Measuring wind speed, which is needed in more sophisticated evaporation and glacial melt models.
- Measuring the temperature of the lake at many points
- Taking into account the sublimation of the glacier,

6. Conclusion

This study shows that insolation drives evaporation at the surface of the lake and glacial melt. Both the evaporation rate and glacial melt affect the level of the lake, and their relative influence varies throughout the day. In the morning, evaporation from the lake surface is more important than the influx of water from the glacier melt. This changes in the afternoon, when glacier melt is more important than evaporation, resulting in an higher lake level. However, this model can be improved in many ways to make it more precise and bring deeper understanding of the processes driving the unique water balance of Cuchilla Lake.

Ongoing research. During the summer of 2012, following the present study recommendations, data was collected from Cuchilla Lake for a 48 hour period.

7. Main references

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8. Acknowledgment

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