Introduction
In many partially glaciated watersheds climate-forced glacier recession has altered and will continue to alter seasonal water availability, leading to profound implications for water supply and ecologic systems. Where available in situ and remotely sensed data are available, observations can be used to understand historical and current changes in these systems. Many hydrologic models allow users to analyze systems beyond spatial and temporal constraints provided by observations alone and provide a platform to infer future change. Until recently, most hydroglacial models lacked an adequate representation of coupled glacio-hydrologic processes. In particular, most did not account for changes in glacier area through the flow of ice. This presents a challenge and demonstrates a need for better developed glacio-hydrological modeling methodology that integrates a dynamic ice flow model into a distributed physically based hydrologic model. Historical applications and future projections are demonstrated for tropical and temperate river basins.

Coupled glacio-hydrological modeling

Integration of Glacier Dynamic Ice Flow in a hydrological model

Historical (1987-2010) Glacio-Hydrological Analysis

Projected glacio-hyrdrologic change: 1987-2100 (RC4.5)

The Zongo River is located in the Cordillera Real of the South American Andes. Glacier melting originating in headwater catchments in the Cordillera Real provides water for downstream drinking water supply, energy production, and ecological services. In particular the Zongo River hosts hydro-electric facilities that provide much of the energy for the nearby heavily populated areas of La Paz and El Alto. We conduct historical and future glacio-hydrological modeling analyses to understand historical and project future patterns of discharge with ongoing glacier recession. This application leverages long-term hydrological and glaciological measurements (conducted by the Institute of Research for Development, IRD) for model implementation and evaluation. The results presented below are described in Frans et al. (in review).

Historical (1916-2005) Contribution of Glacier Melt

The Zongo River Basin: Zongo River, Bolivia

Tropical River Basin: Zongo River, ORA, USA

Conclusions

Tropical: Zongo River Headwaters

• Historically (1987-2010), on average, water derived from glacier melt accounts for 25% of discharge from the watershed on an annual basis and 50% during the dry season (BA).
• Total discharge and discharge sourced from the melting of glacier ice reached a peak around the year 2000 and has started to decline thereafter.

Temperate: Hood River

• Historically (1916-2005) glacier melt contributed up to 79% to discharge at water management locations.
• Declines in total discharge driven by reduced snowmelt began around 1950 and were partially buffered by sustained glacier melt. However, early 21st century glacier melt is projected to decrease intensifying negative trends in total discharge.

References

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Precipitating Tropical Rainfall Measurement Mission

Tropical River Basin: Zongo River Basin: Zongo River, Bolivia

Temperate River Basin: Hood River, OR, USA

The Hood River originates on the northern flanks of Mount Hood, a glaciated stratovolcano which reaches an elevation of 3429 m asl. The Hood River drainage basin (583 km²) hosts agricultural land and aquatic habitats that are vital to the regional economy. The agricultural land is largely composed of perennial crops (e.g. apple and pear orchards and grape vineyards) that have high water demand during summer months and require irrigation. Stream discharge in the basin is in response to flow from the seasonal snowpack and a small storage reservoir that provides agricultural water supply to meet seasonal irrigation demands. The surface and diversion structures are located on streams at high elevations in close proximity to partially glaciated headwater catchments. Water extracted from these streams through five irrigation districts is critical for downstream orchards and resevours.

Historical 1987-2010 projected total discharge and mean monthly discharge

Historical 1987-2010 cumulative net mass balance

Historical 1987-2010 Modeled mean total discharge and mean monthly discharge

The Role of Debris Cover on Glacier Melt

Projection of dry season discharge at Eliot Creek diversion

Future model simulations are forced with transient meteorological data downscaled from 8 CMIP5 GCM outputs using the Multivariate Adaptive Constructual Analysis (MACA) statistical downscaling method (Astinipples and Brown, 2011).

(Top Panel) Projected glacier area and thickness at the end of the year 2000 (2040, 2060, 2080, and 2100. Historical satellite (Landsat) derived glacier extent estimates are shown with a solid black outline.

(Right, a-b) Mean monthly discharge (source: rain, snowmelt, and glacier melt) over the entire response period for (a) the near future (2030-2050) and (b) far future (2080-2010). Discharge volumes projected to decrease by as much as 71% (37%) by the end of the century.

Future model simulations are forced with transient meteorological data downscaled from 8 CMIP5 GCM outputs using the Multivariate Adaptive Constructional Analysis (MACA) statistical downscaling method (Astinipples and Brown, 2011). (1L) Left: Discharge for the entire dry season and (2R) three-month time period of glacier melt (the strongest contribution) for the historical and future time periods (1976-2009). Model results from individual GCMs are shown in light colors and the ensemble mean in dark colors.

Declines in total discharge driven by reduced snowmelt began around 1950 and were partially buffered by sustained glacier melt. However, early 21st century glacier melt is projected to decrease intensifying negative trends in total discharge.