Impacts of snowpack accumulation and summer weather on alpine glacier hydrology

Caroline Aubry-Wake, Dhiraj Pradhananga, John W. Pomeroy

GEWEX 8th Open Science Meeting, Canmore AB, May 3-11 2018
Canadian Rockies: Variable weather and extremes over the last 5 years

<table>
<thead>
<tr>
<th>Context</th>
<th>Field Site</th>
<th>Observation</th>
<th>Modeling</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How does glacier runoff react to inter-annual variability?

For winter accumulation

For summer weather
## Relevance

- Glacier melt is an important contributor to late summer streamflow
- Increasing weather extremes in a changing climate
- Investigating current inter-annual variability can help understanding future water resources
Peyto Glacier

- 2100 - 3190 m a.s.l.
- Weather station with T, RH, U, radiation budget
- Streamflow at outlet
Historical Retreat and Runoff

1966: 14.4 km²
2016: 9.9 km²
Temperature and precipitation, 2013-2017

- High spring precipitation balance low winter snowpack
- Fall precipitation close to 0°C
- Limited comparison
How variable is the Peyto runoff?

<table>
<thead>
<tr>
<th>Year</th>
<th>Observation</th>
<th>Modeling</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>JJSO</td>
<td>JJJSJJOS</td>
<td>JJJSJJOS</td>
</tr>
<tr>
<td>2014</td>
<td>JJSO</td>
<td>JJJSJJOS</td>
<td>JJJSJJOS</td>
</tr>
<tr>
<td>2015</td>
<td>JJSO</td>
<td>JJJSJJOS</td>
<td>JJJSJJOS</td>
</tr>
<tr>
<td>2016</td>
<td>JJSO</td>
<td>JJJSJJOS</td>
<td>JJJSJJOS</td>
</tr>
<tr>
<td>2017</td>
<td>JJSO</td>
<td>JJJSJJOS</td>
<td>JJJSJJOS</td>
</tr>
</tbody>
</table>

**Total Runoff (10^7 m^3)**
- 2013: 3.0
- 2014: 2.7
- 2015: 3.1
- 2016: 3.4
- 2017: 3.5

**Mass balance (mm w.e.)**
- 2013: -910
- 2014: -1630
- 2015: -1538
- 2016: -1844
- 2017: -1410
Cold Region Hydrological Modelling Platform (CRHM)

- Cold region processes
- Process-based, modular, flexible
- Includes avalanches, blowing snow, glacier and snowmelt
- Input data: Weather station
- Run 2013-2017
Model validation

Runoff
- Measured
- Model
RMSE = 0.97 m³ s⁻¹
NSE: 0.46

Mass Balance
- Model
- Stake Point
- <2300 m
- 2300-2500 m
- 2500-2700 m
- >2700 m
Melt components

<table>
<thead>
<tr>
<th>Year</th>
<th>Ice (mm w.e.)</th>
<th>Snow (mm w.e.)</th>
<th>Firn (mm w.e.)</th>
<th>Total (mm w.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>50%</td>
<td>31%</td>
<td>19%</td>
<td>1.56</td>
</tr>
<tr>
<td>2014</td>
<td>46%</td>
<td>41%</td>
<td>13%</td>
<td>1.32</td>
</tr>
<tr>
<td>2015</td>
<td>60%</td>
<td>31%</td>
<td>9%</td>
<td>1.60</td>
</tr>
<tr>
<td>2016</td>
<td>67%</td>
<td>30%</td>
<td>3%</td>
<td>1.34</td>
</tr>
<tr>
<td>2017</td>
<td>65%</td>
<td>32%</td>
<td>3%</td>
<td>1.69</td>
</tr>
</tbody>
</table>
Melt components, snow and rain

Melt components, snow and rain from 2013 to 2017.
What generates streamflow?

Runoff

Seasonal precipitation

Melt Component

Snow and rain
What generates streamflow?

2013: Firn melt

2014: Nearly equal ice and snow

2015: Fall precipitation

2016: High rain and melt

2017: High snowmelt
What generates streamflow?

- 2013: Firn melt
- 2014: Nearly equal ice and snow
- 2015: Fall precipitation
- 2016: High rain and melt
- 2017: High snowmelt
What generates streamflow?

2013: Firn melt
2014: Nearly equal ice and snow
2015: Fall precipitation
2016: High rain and melt
2017: High snowmelt
<table>
<thead>
<tr>
<th>Context</th>
<th>Field Site</th>
<th>Observation</th>
<th>Modeling</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>2014</td>
<td>2015</td>
<td>2016</td>
<td>2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**What generates streamflow?**

- **2013:** Firn melt
- **2014:** Nearly equal ice and snow
- **2015:** Fall precipitation
- **2016:** High rain and melt
- **2017:** High snowmelt
<table>
<thead>
<tr>
<th>Year</th>
<th>Context</th>
<th>Field Site</th>
<th>Observation</th>
<th>Modeling</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Firn melt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>Nearly equal ice and snow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>Fall precipitation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>High rain and melt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>High snowmelt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What generates streamflow?
Summary

• Combining fieldwork and modeling provides further insights on the sources and variability of glacier runoff
• At Peyto, glacier melt still buffers streamflow, even though total runoff is less than historical
• Runoff composition varies considerably depending on seasonal conditions
• Years of low snow can be buffered by high summer rain, and vice-versa

Thank you,

Questions?