Runoff simulation in a glacier dominated watershed using semi distributed hydrological model

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Introduction
• Background of the research
• Research Questions

Study area
• Highlights of study area

Methodology
• Data used and sources
• First simulation
• Process comparison
• Hydrograph separation
• Year studied

Results
• Calibration period
• Validation period

Discussion
• Result comparison

Conclusion
• Key findings
• Next steps

Acknowledgement
40 % of stream runoff is coming from snow and glacier melt in the Rhone valley [Huss et al. 2009]

In Switzerland, 84 out of 85 glaciers under observation became shorter [WGMS, 2008]

55 % of Swiss energy from Hydropower. [Schleiss et al. 2007]

Alarming negative mass balance trend observed in the Rhone Glacier [Funk et al 2008]

Assessing climate change impact on quantity and quality of water [www.acqwa.ch]
How well hydrological models (SWAT-RS 3.0) are capable simulating runoff in Upper Rhone River

Taking into account
  • Glacier
  • Orographic Precipitation
  • Snow melt

Long term forecast for water status for glacier dominated Upper Rhone watershed

Taking into account
  • Climate change scenarios (IPCC, Ensemble/Prudance)
  • Energy driven scenarios
  • Land use scenarios (EnviroGRID)
Watershed area: 39.60 km$^2$

Elevation:
min 1758 m
max 3617 m

Land use:
Glacier (48%)
Solid rocks (14%)
### DATA USED AND SOURCES

<table>
<thead>
<tr>
<th>Data type</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Elevation Model (DEM)</td>
<td>Swiss-topo (grid cell: 25 m · 25 m) <a href="http://www.swisstopo.ch">www.swisstopo.ch</a></td>
</tr>
<tr>
<td>Land use</td>
<td>FOEN (grid cell: 100 m · 100 m) <a href="http://www.bfs.admin.ch">http://www.bfs.admin.ch</a></td>
</tr>
<tr>
<td>Soil type</td>
<td>FOEN (grid cell: 100 m · 100 m) <a href="http://www.bfs.admin.ch">http://www.bfs.admin.ch</a></td>
</tr>
<tr>
<td>River &amp; channel network</td>
<td>FOEN (grid cell: 100 m · 100 m) <a href="http://www.bfs.admin.ch">http://www.bfs.admin.ch</a></td>
</tr>
<tr>
<td>Hydrometeorlogic data</td>
<td>MeteoSwiss <a href="http://www.meteosuisse.admin.ch">http://www.meteosuisse.admin.ch</a></td>
</tr>
<tr>
<td>River flows</td>
<td>FOEN, Switzerland <a href="http://www.hydrodaten.admin.ch">http://www.hydrodaten.admin.ch</a></td>
</tr>
</tbody>
</table>

### 3 Sub basin 25 H RU
YEAR OF STUDY

- Model Interface: ArcSWAT 2009
- Total year of study: 1997-2009
- Warm up Period: 1997-2000
- Calibration Period: 2001-2006
- Validation Period: 2007-2009
- Time step: Monthly Average, Daily Average
- Model evaluation: Visually (graph fitting), Statistically
Time lag of rising limb
Systematic underestimation
Sharp dropdown of recession limb
Secondary peaks
[Jordan et al, 2007]
<table>
<thead>
<tr>
<th>Process</th>
<th>SWAT</th>
<th>RS 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface runoff</td>
<td>(i) Curve Number (CN)</td>
<td>Kinematic wave over a inclined plan (SWMM)</td>
</tr>
<tr>
<td></td>
<td>(ii) Green and Ampt approach</td>
<td></td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>(i) Priestley-Taylor</td>
<td>Turc method</td>
</tr>
<tr>
<td></td>
<td>(ii) Penman-Monteith</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(iii) Hargreaves</td>
<td></td>
</tr>
<tr>
<td>Flow routing</td>
<td>(i) Variable storage coefficient</td>
<td>Kinematic wave</td>
</tr>
<tr>
<td></td>
<td>(ii) Muskingum approach</td>
<td>St-Venant dynamic wave</td>
</tr>
<tr>
<td>Snow melt</td>
<td>Temperature Index</td>
<td>Enhanced Temperature Index with 2 reservoirs</td>
</tr>
<tr>
<td></td>
<td><strong>Temperature Index with Elevation</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy budget based SNOW 17</td>
<td></td>
</tr>
<tr>
<td>Glacier Melt</td>
<td>?</td>
<td>Enhanced Temperature Index</td>
</tr>
</tbody>
</table>
Time lag of rising limb no longer exists
Summer overestimation, Winter underestimation
Secondary peaks

(Huss, et al., 2009)
Tracers are conservative (no chemical reactions);
All components have significantly different concentrations for at least one tracer;
Tracer concentrations in all components are temporally constant or their variations are known;
Tracer concentrations in all components are spatially constant or treated as different components;
Simultaneous Equations

\[ f_1 + f_2 + f_3 = 1 \]
\[ C_1^1 f_1 + C_2^1 f_2 + C_3^1 f_3 = C_t^1 \]
\[ C_1^2 f_1 + C_2^2 f_2 + C_3^2 f_3 = C_t^2 \]

Solutions

\[ f_1 = \frac{(C_t^1 - C_3^1)(C_2^2 - C_3^2) - (C_2^1 - C_3^1)(C_t^2 - C_3^2)}{(C_1^1 - C_3^1)(C_2^2 - C_3^2) - (C_2^1 - C_3^1)(C_1^2 - C_3^2)} \]
\[ f_2 = \frac{C_1^1 - C_3^1}{C_2^1 - C_3^1} - \frac{C_1^1 - C_3^1}{C_2^1 - C_3^1} f_1 \]
\[ f_3 = 1 - f_1 - f_2 \]

- \( f \) - Discharge Fraction
- \( C \) - Tracer Concentration
- Subscripts - # Components
- Superscripts - # Tracers
Co-relation matrix formation
**Principal component analysis**

Proportion of Variance

- PC 1 = 0.7095
- PC 2 = 0.2347
- PC 3 = 0.04696
- PC 4 = 0.00879

94 percent variability can be explained through first 2 axis
### PCA Matlab

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>[COEFF,SCORE] = princomp(X)</code></td>
<td></td>
</tr>
<tr>
<td><code>[COEFF,SCORE,latent] = princomp(X)</code></td>
<td></td>
</tr>
<tr>
<td><code>[COEFF,SCORE,latent,tsquare] = princomp(X)</code></td>
<td></td>
</tr>
<tr>
<td><code>... = princomp(X,'econ')</code></td>
<td></td>
</tr>
</tbody>
</table>

### PCA R (ade4)

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>data2&lt;-read.table(&quot;data2.txt&quot;,header=T)</td>
<td>attach(data2)</td>
</tr>
<tr>
<td>attach(data2)</td>
<td></td>
</tr>
<tr>
<td>names(data2)</td>
<td></td>
</tr>
<tr>
<td>pca_data2 &lt;- dudi.pca(data2,scannf=T)</td>
<td></td>
</tr>
<tr>
<td>pca_data2</td>
<td></td>
</tr>
<tr>
<td>pca_data2$li</td>
<td></td>
</tr>
<tr>
<td>pca_data2$co</td>
<td></td>
</tr>
<tr>
<td>s.corcircle(pca_data2$co)</td>
<td></td>
</tr>
<tr>
<td>par(mfrow=c(2,2))</td>
<td></td>
</tr>
<tr>
<td>s.corcircle(pca_data2$co)</td>
<td>pca_data2$eig</td>
</tr>
</tbody>
</table>

### PCA R (prcomp)

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>data2&lt;-read.table(&quot;data2.txt&quot;,header=T)</td>
<td>attach(data2)</td>
</tr>
<tr>
<td>attach(data2)</td>
<td></td>
</tr>
<tr>
<td>names(data2)</td>
<td></td>
</tr>
<tr>
<td>prcomp(data2)</td>
<td></td>
</tr>
<tr>
<td>summary(prcomp(data2, scale = TRUE))</td>
<td></td>
</tr>
</tbody>
</table>
## Optimized Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Range</th>
<th>Optimized value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFTMP</td>
<td>Snowfall temperature [°C]</td>
<td>−5,+5</td>
<td>1.221</td>
</tr>
<tr>
<td>SNOEB</td>
<td>Initial snow water content [mm]</td>
<td>0, 300</td>
<td>150</td>
</tr>
<tr>
<td>SMTMP</td>
<td>Snow melt base temperature [°C]</td>
<td>−5,+5</td>
<td>2.823</td>
</tr>
<tr>
<td>TIMP</td>
<td>Snow pack temperature lag factor [−]</td>
<td>0, 1</td>
<td>0.032</td>
</tr>
<tr>
<td>SMFMN</td>
<td>Melt factor for snow on December 21st [mm H₂O/°C day]</td>
<td>0, 10</td>
<td>4.825</td>
</tr>
<tr>
<td>SMFMX</td>
<td>Melt factor for snow on June 21st [mm H₂O/°C day]</td>
<td>0, 10</td>
<td>3.319</td>
</tr>
<tr>
<td>SNOCOVMX</td>
<td>Minimum snow water content that corresponds to 100% snow cover [mm]</td>
<td>0, 500</td>
<td>300</td>
</tr>
</tbody>
</table>

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### Study area

[Text not visible in the image]

\[ \text{NSE} > 0.5, \text{RSR} \leq 0.70, \text{PBIAS} = \pm 25\% \]

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Equation</th>
<th>SWAT</th>
<th>RS 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSE</td>
<td>( \text{NSE} = 1 - \left[ \frac{\sum_{i=1}^{n} (X_{i}^{\text{obs}} - X_{i}^{\text{sim}})^2}{\sum_{i=1}^{n} (X_{i}^{\text{obs}} - X_{i}^{\text{mean}})^2} \right] )</td>
<td>77</td>
<td>93</td>
</tr>
<tr>
<td>PBIAS</td>
<td>( \text{PBIAS} = \left[ \frac{\sum_{i=1}^{n} (X_{i}^{\text{obs}} - X_{i}^{\text{sim}}) \times 100}{\sum_{i=0}^{n} (X_{i}^{\text{obs}})} \right] )</td>
<td>5.43</td>
<td>5.26</td>
</tr>
<tr>
<td>RSR</td>
<td>( \text{SR} = \frac{\text{RMSE}}{\text{STDEV}<em>{\text{obs}}} = \left[ \frac{\sqrt{\sum</em>{i=1}^{n} (X_{i}^{\text{obs}} - X_{i}^{\text{sim}})^2}}{\sqrt{\sum_{i=1}^{n} (X_{i}^{\text{obs}} - X_{i}^{\text{mean}})^2}} \right] )</td>
<td>0.46</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Where \( X_{i}^{\text{obs}} \) = observed variable (flow in m\(^3\)s\(^{-1}\))

\( X_{i}^{\text{sim}} \) is the simulated variable (flow in m\(^3\)s\(^{-1}\))

\( X_{i}^{\text{mean}} \) is the mean of \( n \) values and \( n \) is the number of observations.
Key Findings..

- Model generated runoff has close match with measured runoff [NSE varies between 77 (daily) to 84 (monthly)]

- Glacier can be treated as reservoir and the outflow can be routed through reservoir

- Application of Elevation band has significant impact on snow/glacier melt process [Efficiency varies based on number of elevation band selection]

- Sensitive parameters are mostly related to snow/glacier melt process [SM TMP, SM FM N, SM FM X..]
Extend the calibration for entire Rhone Link with species community
Sub daily calibration (Hydropower optimization)
Climate change scenario implementation (Prudence)
Land use change scenario implementation (enviroGRIDS)
1. was there any point source? if so what were they? how did you get the point source data? was it daily or monthly?
2. what were the final calibration parameter? I see the sensitivity list?
3. was it using auto calibration? if so what are the uncertainty?
4. how does rock parameters help in final calibration?
5. how was the glacier area was estimated?
6. did you implement elevation bands? also permanent snow depths?

hope some of these questions help to make your presentation better.
LIMITATIONS

1. Availability of spatial extents and thickness
2. Hydrograph separation for one melt season
3. Expensive equipment's
A c k n o w l e d g m e n t s...

Main promoter
Dr. Anthony Lehmann
University of Geneva

Co promoters
Dr. Emmanuel Castella
University of Geneva
Dr. Karim Abbaspour
EAWAG, Switzerland

Resource persons
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Edric, Switzerland
Dr. Stéphane Goyette
University of Geneva
Dr. Chetan Maringanti
University of Geneva

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Introduction
Study area
Methodology
Results
Discussion
Conclusion
Acknowledgement