Impacts of historic climate variations on streamflow characteristics in Icelandic rivers

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Objective

- To analyse the hydrologic response of 11 river basins in Iceland to past climate variations, especially temperature variations.
  - Streamflow characteristics
    » Discharge seasonality
    » Mean annual discharge
    » Number of floods (POT)
  - Snow storage characteristics
    » Annual maximum
    » Snow cover duration
  - Daily snowmelt rates
    » Annual maxima
  - Daily glacial melt rates
    » Annual maxima
    » Duration of melting period

25% warmest years
25% coldest years
1971-2000
11 River basins

- Direct runoff rivers
- Spring-fed rivers
- Glacial rivers (5)
- Lakes

Size: 42 km² – 5687 km²
Mean elevation: 163 m – 863 m
Data


- Gridded temperature: daily, 1 km (1949-2007)
  - Enhanced spatial interpolation (DEM)
    - Spline + lapse rate 6.5°C/km

- Gridded precipitation: daily, 1 km (1958-2006)
  - LT-model (Smith & Barstad 2004)
    - Input: ECMWF precipitation, wind & temperature; DEM
    - CE project (Crochet et al., 2007, Jóhannesson et al., 2007)
Derived data (1958-2006)
(daily, 1 km², catchment averaged)

Precipitation
Temperature

Snow
(SWE)

Rain

Snow storage
SWE

Snowmelt

Ice melt

\[
\begin{align*}
T & \leq T_0 \\
\begin{cases}
DDE_{snow}(T-T_0) & \text{if } T > T_0 \\
0 & \text{if } T \leq T_0
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\begin{cases}
DDE_{ice}(T-T_0) & \text{if } T > T_0 \\
0 & \text{if } T \leq T_0
\end{cases}
\end{align*}
\]
Mean annual temperature difference

Difference relative to 1971-2000

- $+1^\circ C$ (25% warmest)
- $-0.7^\circ C$ (25% coldest)

Difference between 25% warmest and 25% coldest years

$+1.7^\circ C$
Austari-Jökulsá, 12% glacier covered
Northern part of central highlands

Snow storage seasonality

Mean annual maximum

Snowmelt (solid) and glacial melt (dashed) seasonality

Mean annual maximum

→ 20% Maximum 1971-2000

→ 20% glacial peak of melting 1971-2000
Mean yearly maximum snow storage difference between 25% warmest and 25% coldest years

Peak magnitude difference
100(Warmest-Coldest) / Coldest

Peak timing difference
Warmest-coldest
24 days earlier

-20% -80% 

+1.7°C

→ 24 days earlier
Mean snow cover duration

- Mean duration: -50 days (23% shorter)

Difference in snow cover duration between 25% warmest and 25% coldest years:

- +1.7°C

-50 days (23% shorter)
Mean yearly maximum snowmelt rate

Magnitude difference
100(Warmest - Coldest)/Coldest

-40 %

Timing difference
between 25% warmest and 25% coldest years

-37 days

+1.7°C
Average glacial snow and ice melt

Difference in average duration of glacial melt period between 25% warmest and 25% coldest years

~ 1 month longer

+1.7°C

% Change in mean yearly maximum glacial melt between 25% warmest and 25% coldest years

⇒ +23%
Average discharge seasonality

VHM-10 (Svartá), North (ice free)

Surface runoff (snowmelt + rain)

VHM-144 (Austari-Jökulsá), central N, glacier covered

Surface runoff (snowmelt + glacial melt + rain)

Discharge

ΔQpeak

Δtiming

All years
1971-2000
25% coldest
25% warmest
% Change in average daily discharge in coldest and warmest years relative to 1971-2000

Ice free North
D+S
VHM-10
VHM-19
VHM-26

Glacier covered Central Highlands
D+G+S
VHM-144
VHM-145
VHM-96

Ice free SW
D+S+(L)
VHM-81
VHM-301

Spring-fed SW Highlands
S+(G)+D
VHM-66 (G)
VHM-64 (G)
VHM-43
Change in mean yearly maximum discharge

$\Delta Q_{\text{peak}}$

$\frac{100(\text{warmest-coldest})}{\text{coldest}}$

$\rightarrow +8\%$

$\rightarrow -25\%$

$+1.7^\circ\text{C}$

$\Delta \text{timing}$

$\text{warmest-coldest}$

$\rightarrow -12\text{ days}$

$\rightarrow -111\text{ days}$
Mann-Whitney test between 25% coldest and 25% warmest years
$\alpha=10\%$ (open circle), $\alpha=5\%$ (filled circle)

- Annual Discharge
  - Not different
  - Different $\rightarrow +12\%$

- Annual Precipitation
  - Not different
  - Different $\rightarrow +15\%$
  +1.7°C
Glacial runoff contribution to annual discharge

$\Rightarrow \sim 20\%$

+1.7°C

$\Rightarrow +43\%$
Change in number of flood events (POT) between 25% warmest and 25% coldest years

POT > median Q peaks (71-00)

\[ \rightarrow +22\% \]

+1.7°C

POT > mean annual maximum Q (71-00)

\[ \rightarrow +156\% \]

\[ \rightarrow -56\% \]
Summary

• All catchments showed signs of great sensitivity to relatively modest mean annual temperature variations (+/- 1°C; +1.7°C)

• Temperature variations impact on:
  – Snow storage development and snowmelt rates
  – Runoff contribution from glaciers
  – Streamflow characteristics:
    • Seasonality
      – Annual peak discharge timing & magnitude shifts
      – Warmest years: reduced amplitude between base and peak flows
      – Coldest years: enhanced amplitude between base and peak flows
  • Annual discharge in the South (Precipitation)
  • Number of flood events (moderate and extremes)