Snowmelt rate and continuity determine the intra-annual variability and magnitude of streamflow in three alpine watersheds in the western U.S.

Xiaohua Chen[1], Guoping Tang[1], Tao Chen[1], and Xiangyu Niu[1]

[1]Sun Yat-Sen University

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Abstract

In semiarid to arid regions of the western U. S., the availability and variability of river flow are highly subject to shifts in snow accumulation and ablation in alpine watersheds. This study aims to examine how shifts in snowmelt rate (SMR) and snow continuity, an indicator of the consistent existence of snow on the ground, affect snow-driven streamflow dynamics in three alpine watersheds in the U.S. Great Basin. To achieve this end, the coupled hydro-ecological simulation system (CHESS) is used to simulate river flow dynamics and multiple snow metrics are calculated to quantify the variation of snowmelt rate and snow continuity, the latter of which is measured, respectively, by snow persistence (SP), snow residence time (SRT) and snow season length (SSL). Then, a new approach is proposed to partition streamflow into snow-driven and rain-driven streamflow. The statistical analyses indicate that the three alpine watersheds experienced a downward trend in SP, SRT, SSL and SMR during the study period of 1990-2016 due to regional warming. As a result, the decrease in SMR and the decline in snow continuity shifted the day of 25% and 50% of the snow-driven cumulative discharge as well as peak discharge toward an earlier occurrence. Besides, the magnitudes of snow-driven annual streamflow, summer baseflow and peak discharge also decreased due to the declined snow continuity and the reduced snowmelt rate. Overall, by using multiple snow and flow metrics as well as by partitioning streamflow into snow-driven and rain-driven flow via the newly proposed approach, we found that snowmelt rate and snow continuity determine the streamflow hydrographs and magnitudes in the three alpine watersheds. This has important implications for water resource management in the snow-dominated region facing future climate warming given that warming can significantly affect snow dynamics in alpine watersheds in semiarid to arid regions.

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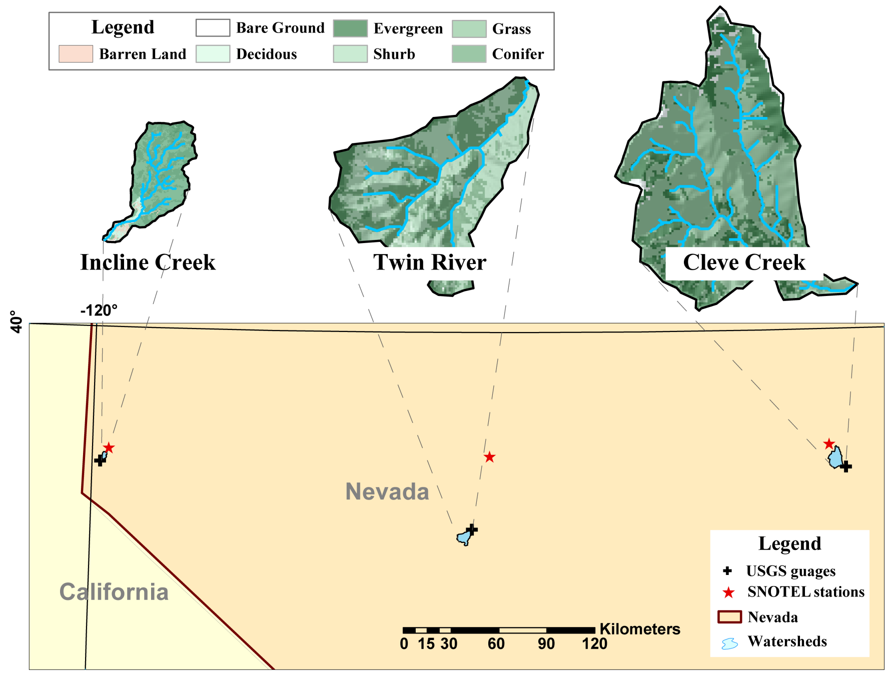
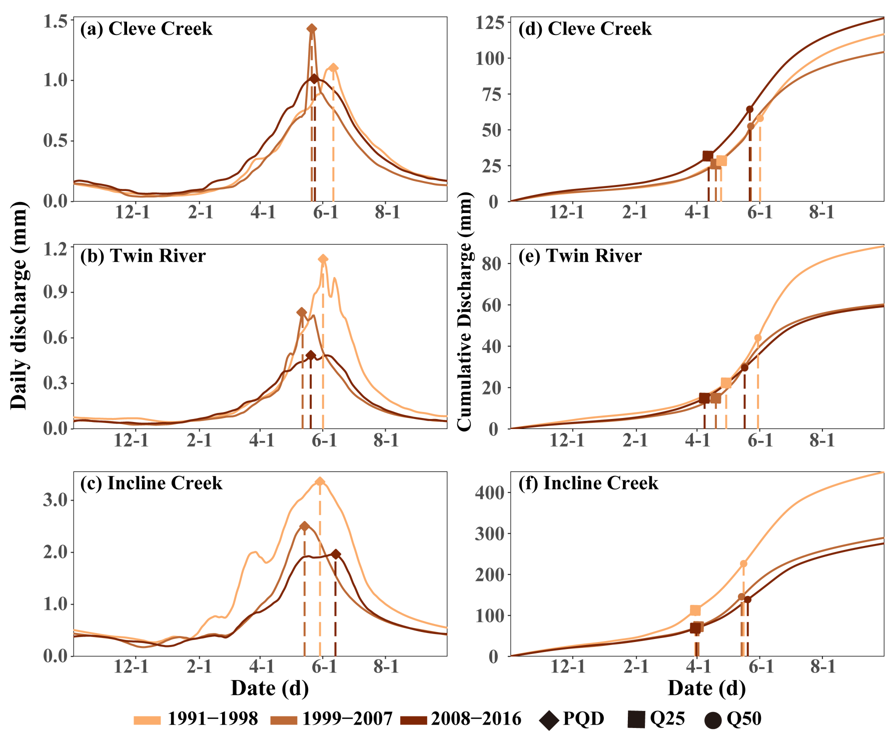
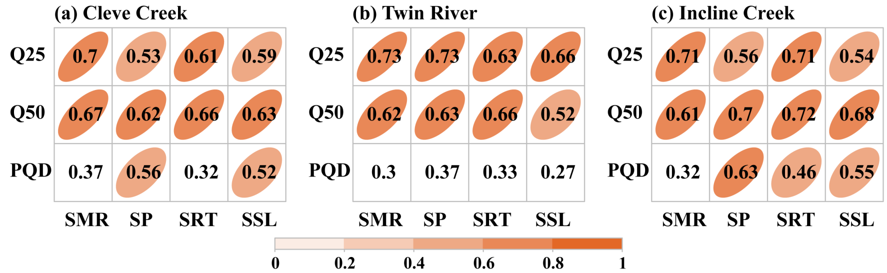
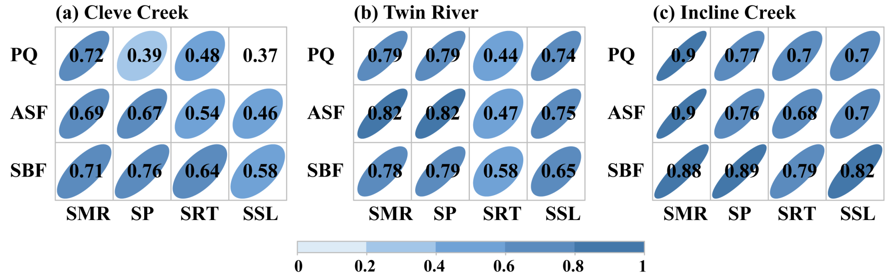
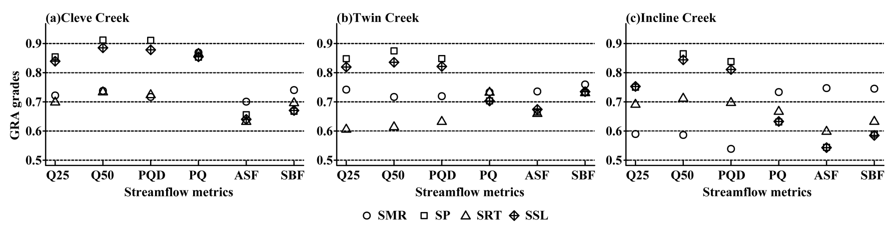
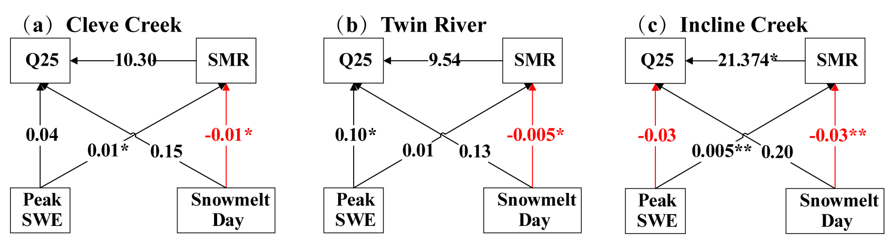

Legend
Bare Ground
Evergreen
Grass
Barren Land
Decidous
Shurb
Conifer
Incline Creek
Twin River
Cleve Creek
40°
-120°
Nevada
California
Kilometers
0 15 30 60 90 120
Legend
USGS guages
SNOTEL stations
Nevada
Watersheds

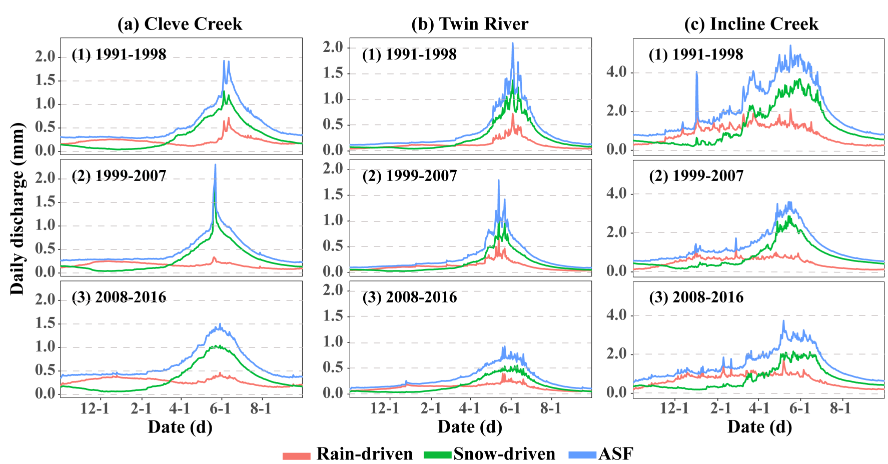

(a) Cleve Creek
(b) Twin River
(c) Incline Creek
(d) Cleve Creek
(e) Twin River
(f) Incline Creek
Daily discharge (mm)
Cumulative Discharge (mm)
12-1
2-1
4-1
6-1
8-1
Date (d)
1991−1998
1999−2007
2008−2016
PQD
Q25
Q50

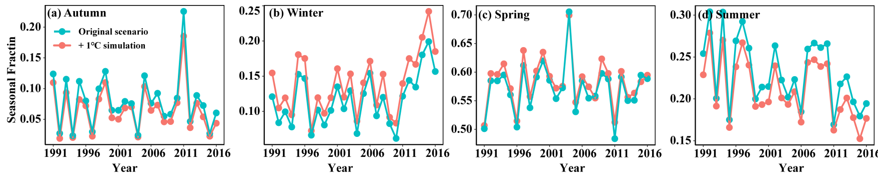

(a) Cleve Creek
(b) Twin River
(c) Incline Creek
Q25 0.7 0.53 0.61 0.59
Q50 0.67 0.62 0.66 0.63
PQD 0.37 0.56 0.32 0.52
Q25 0.73 0.73 0.63 0.66
Q50 0.62 0.63 0.66 0.52
PQD 0.3 0.37 0.33 0.27
Q25 0.71 0.56 0.71 0.54
Q50 0.61 0.7 0.72 0.68
PQD 0.32 0.63 0.46 0.55
SMR SP SRT SSL
0 0.2 0.4 0.6 0.8 1


(a) Cleve Creek
(b) Twin River
(c) Incline Creek
PQ 0.72 0.39 0.48 0.37
ASF 0.69 0.67 0.54 0.46
SBF 0.71 0.76 0.64 0.58
PQ 0.79 0.79 0.44 0.74
ASF 0.82 0.82 0.47 0.75
SBF 0.78 0.79 0.58 0.65
PQ 0.9 0.77 0.7 0.7
ASF 0.9 0.76 0.68 0.7
SBF 0.88 0.89 0.79 0.82
SMR SP SRT SSL
0 0.2 0.4 0.6 0.8 1


(a)Cleve Creek
(b)Twin Creek
(c)Incline Creek
GRA grades
0.5
0.6
0.7
0.8
0.9
Q25 Q50 PQD PQ ASF SBF
Streamflow metrics
SMR SP SRT SSL


(a) Cleve Creek
Q25
10.30
SMR
0.04
0.01*
0.15
-0.01*
Peak SWE
Snowmelt Day
(b) Twin River
Q25
9.54
SMR
0.10*
0.01
0.13
-0.005*
Peak SWE
Snowmelt Day
(c) Incline Creek
Q25
21.374*
SMR
-0.03
0.005**
0.20
-0.03**
Peak SWE
Snowmelt Day


(a) Cleve Creek
(b) Twin River
(c) Incline Creek
(1) 1991-1998
(2) 1999-2007
(3) 2008-2016
Daily discharge (mm)
0.0
0.5
1.0
1.5
2.0
4.0
12-1 2-1 4-1 6-1 8-1
Date (d)
Rain-driven
Snow-driven
ASF



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