Role of Runoff Ratio in the Sensitivity of Streamflow

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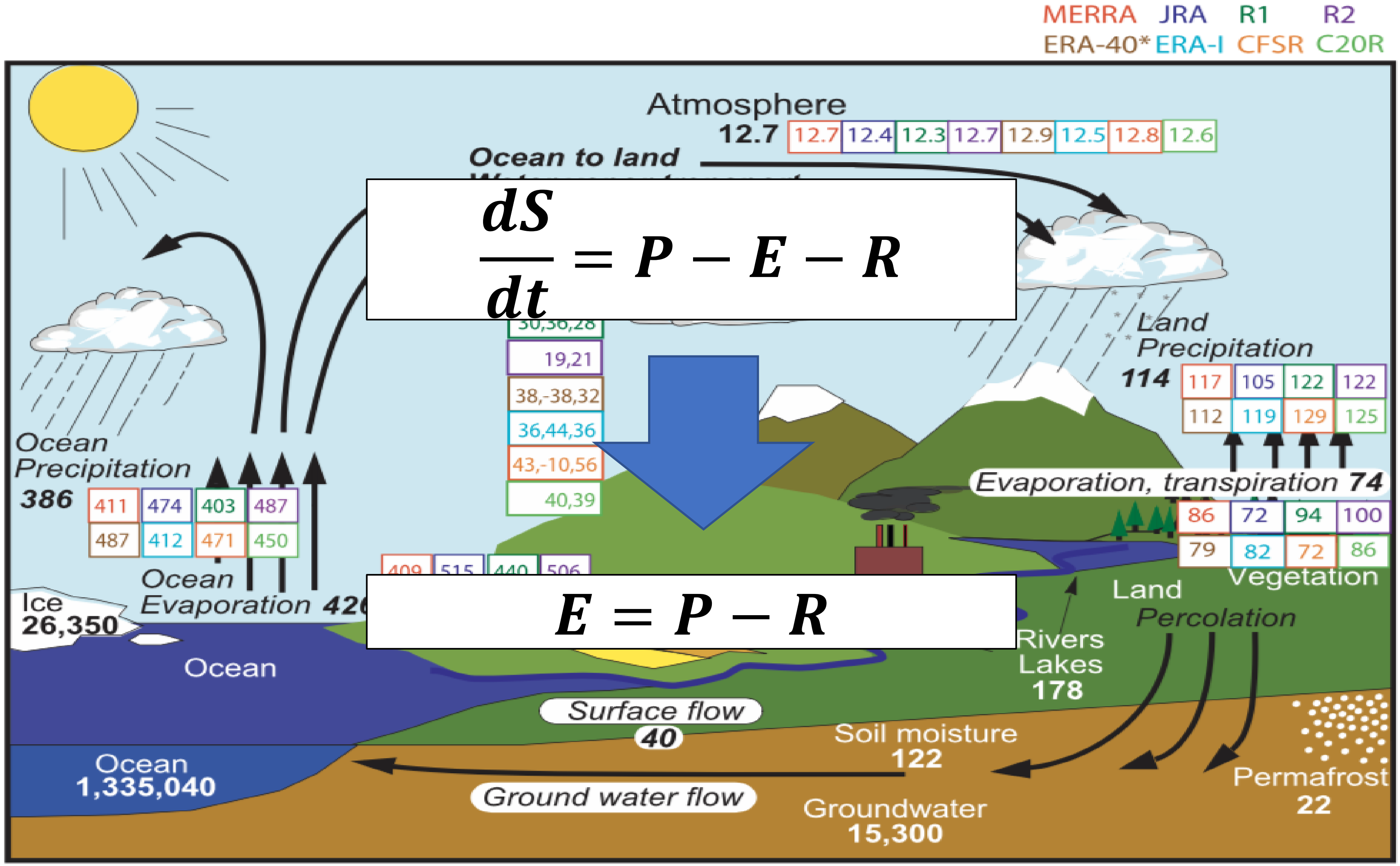
Hydrological cycle



$$\frac{dS}{dt} = P - E - R$$

$$E = P - R$$

Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s

(Trenberth et al. 2011)

Relationship between precipitation and streamflow changes according to runoff ratio

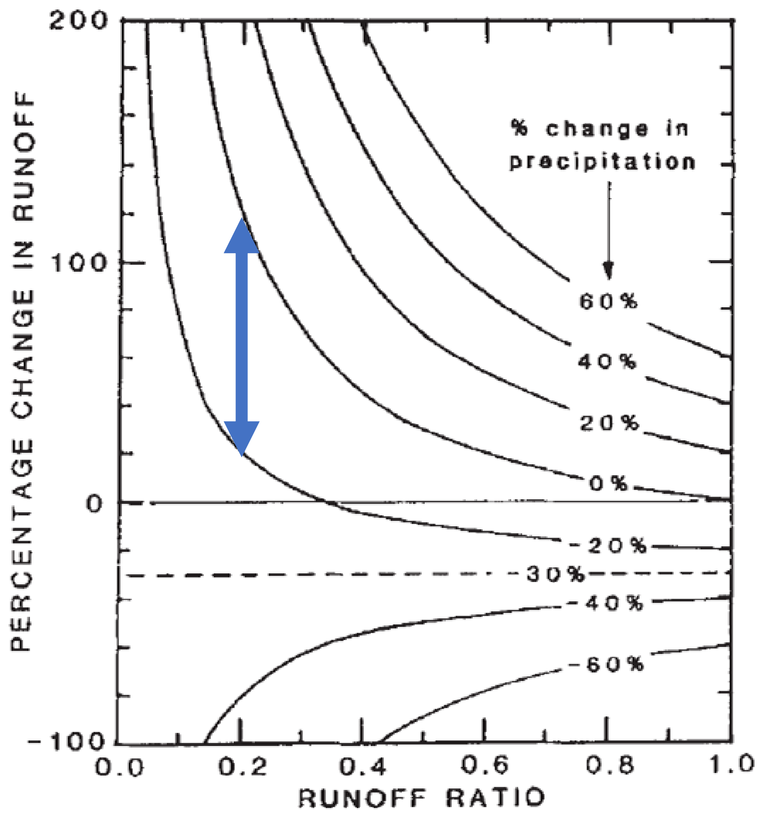
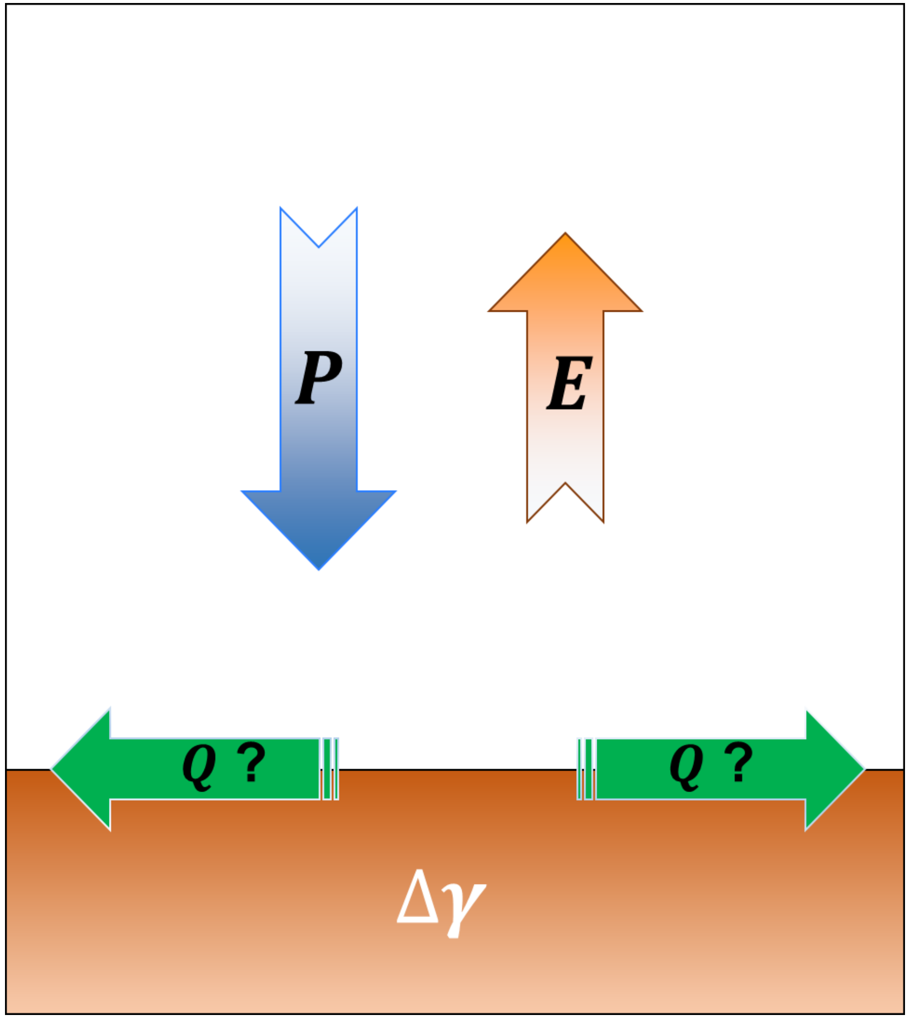


Fig. 1 Runoff changes due to changes in precipitation from a 60% reduction ($\alpha = 0.4$) to a 60% increase ($\alpha = 1.6$) assuming a maximum direct CO_2 effect on evapotranspiration ($a = 1$ in equation (5)) and no other changes in evapotranspiration ($\beta_1 = \beta_2 = 1$).



In this study, the sensitivity of streamflow due to the runoff ratio is investigated under the climatological changes in precipitation and evaporation

Scientific questions

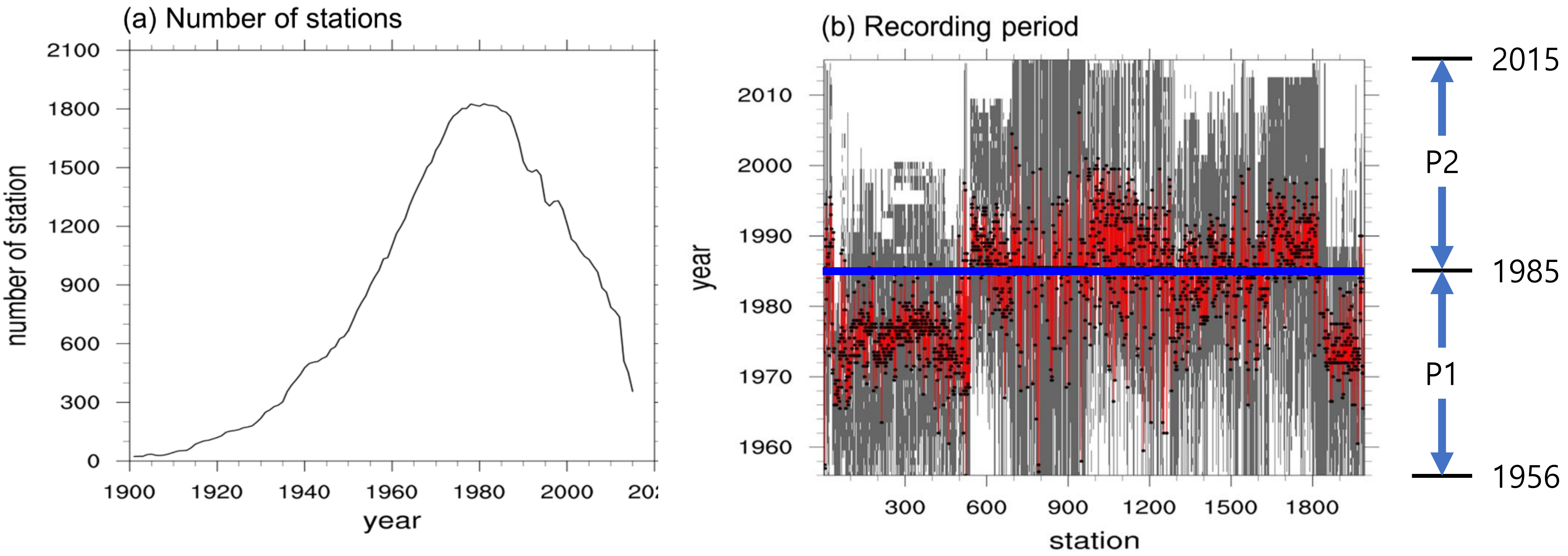
1) Is the hydrologic sensitivity to change of runoff ratio quantified given climate change and runoff ratio at the climate regime scales?

2) How does the impact of the change in runoff ratio on the hydrologic sensitivity vary across the climate regimes?

3) Are past changes in runoff ratio informative in identifying vulnerable regions to drought and flood given the change in precipitation and evapotranspiration?

Data & Methods

- **Observed streamflow data (GRDC, Global Runoff Data Centre)**



- Number of stream gages : 1,636 (without artificial structures)

Data & Methods

- **Climate change**

	C1	C2	C3	C4	C5	C6
Precipitation change ($\boldsymbol{\alpha}$)	Decrease	Decrease	Decrease	Increase	Increase	Increase
Evaporation change ($\boldsymbol{\beta}$)	Increase	Decrease	Decrease	Increase	Increase	Decrease
$\boldsymbol{\beta/\alpha}$	$\boldsymbol{\beta/\alpha}<0$	$\boldsymbol{\beta/\alpha}<1$	$\boldsymbol{\beta/\alpha}>1$	$\boldsymbol{\beta/\alpha}>1$	$\boldsymbol{\beta/\alpha}<1$	$\boldsymbol{\beta/\alpha}<0$

$* \ \alpha = dP/\overline{P_{P1}}, \quad \beta = dAET/\overline{AET_{P1}}$

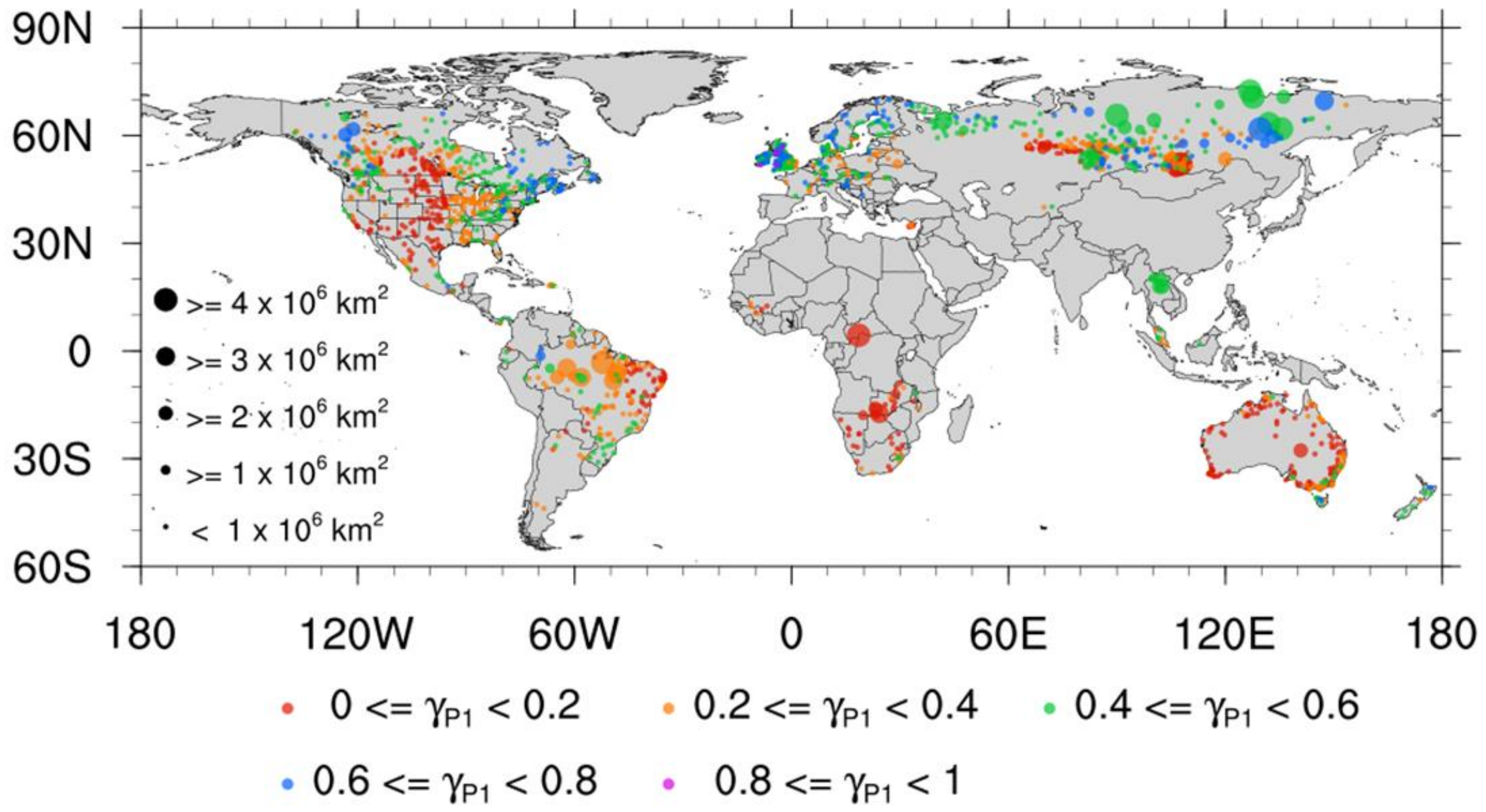
- **Change in streamflow by runoff-ratio (γ) change**

$$\delta_c = \frac{\alpha_c + (\gamma_{c,P1} - 1)\beta_c}{\gamma_{c,P1}}$$

$$\boldsymbol{\delta_{\Delta\gamma_c}} = \frac{\alpha + (\gamma_{c,A} - 1)\beta}{\gamma_{c,A}} - \frac{\alpha + (\gamma_{c,P1} - 1)\beta}{\gamma_{c,P1}}$$

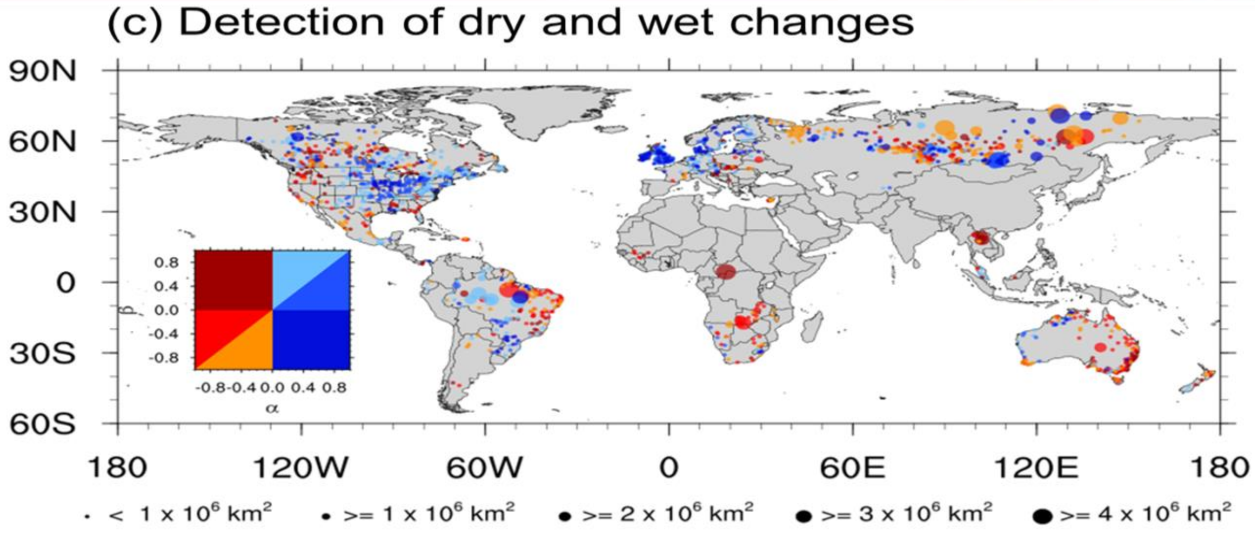
$$= \frac{(\gamma_A - \gamma_{P1})(\beta - \alpha)}{\gamma_{c,P1}\gamma_A} = \boldsymbol{\frac{\Delta\gamma_c(\beta - \alpha)}{\gamma_{c,P1}(\gamma_{c,P1} + \Delta\gamma_c)}}$$

Distribution of runoff ratio in the P1 period

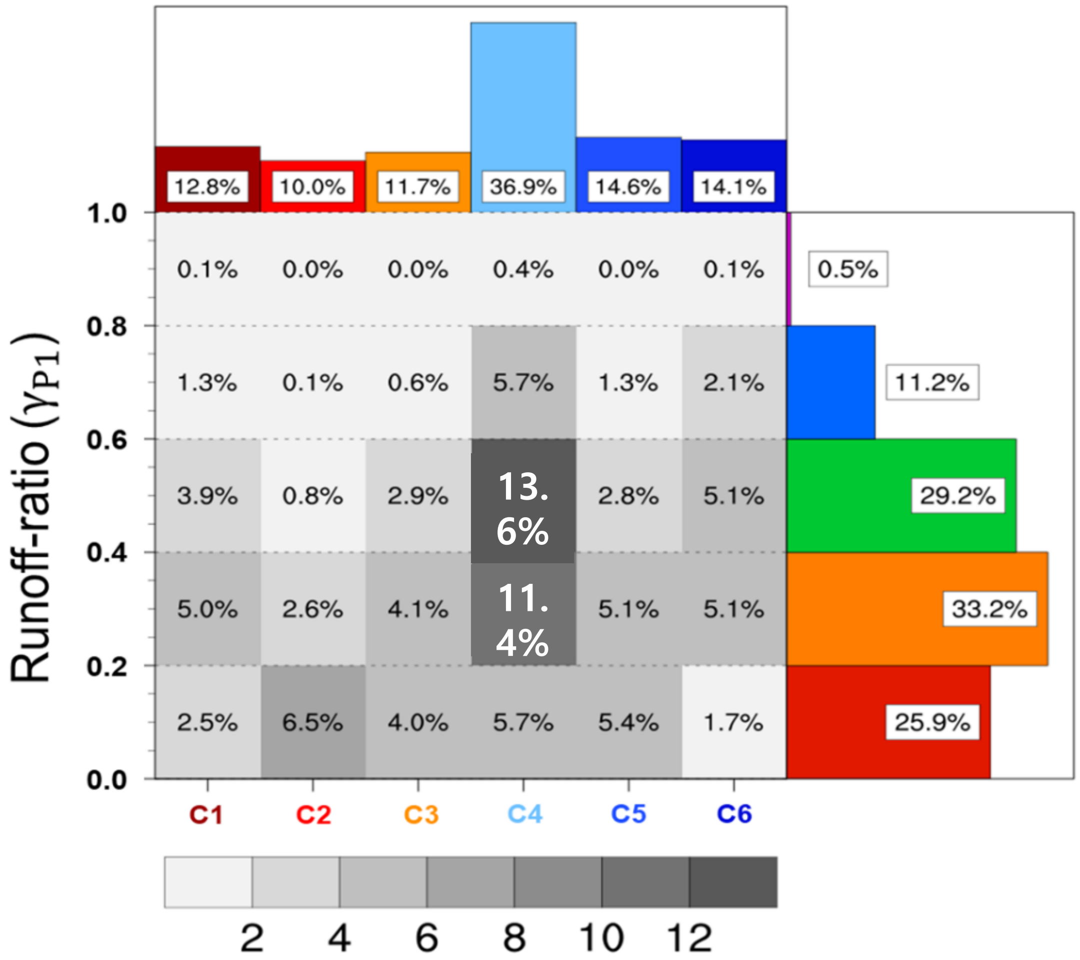


- Gage stations with runoff ratio less than 0.4 are mostly distributed in desert areas.

Climate changes in precipitation and evaporation



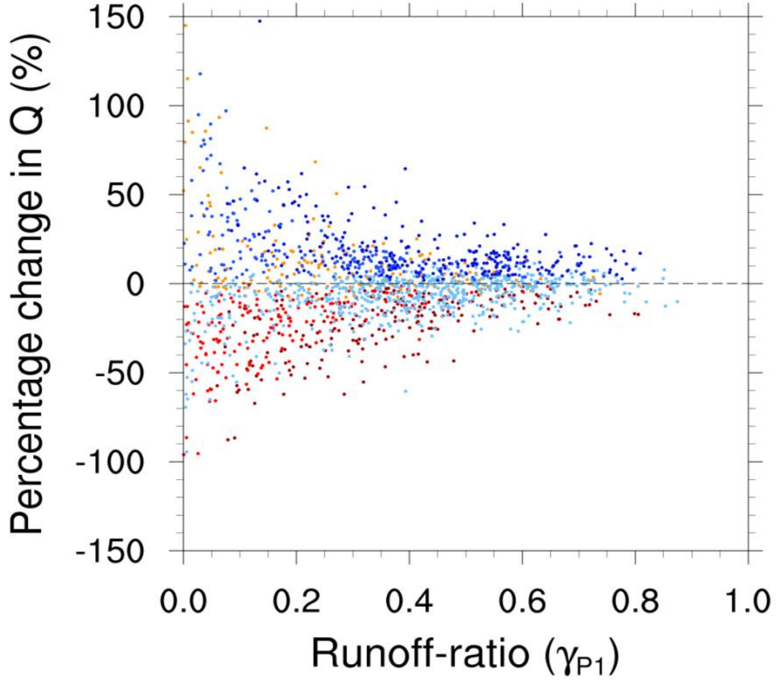
	C1	C2	C3	C4	C5	C6
Precipitation change (α)	Decrease	Decrease	Decrease	Increase	Increase	Increase
Evaporation change (β)	Increase	Decrease	Decrease	Increase	Increase	Decrease
β/α	$\beta/\alpha<0$	$\beta/\alpha<1$	$\beta/\alpha>1$	$\beta/\alpha>1$	$\beta/\alpha<1$	$\beta/\alpha<0$



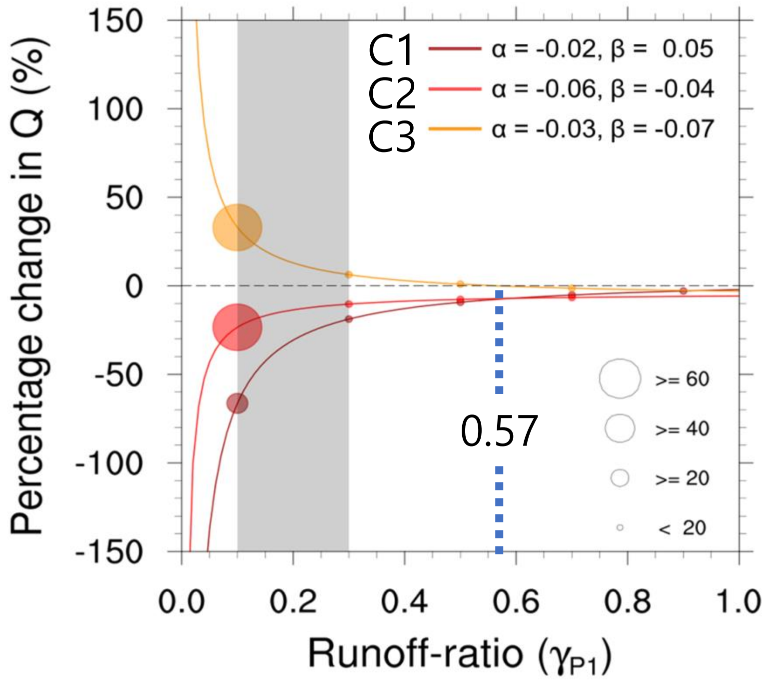
- Case 4 climate change occurred in 36.9% over the globe in the last 60 years, and this change is detected in the central and eastern US, central Europe, and the Amazon rainforest where the runoff ratio ranges from 0.2 to 0.6.

Relationship between streamflow change and runoff ratio in climate change

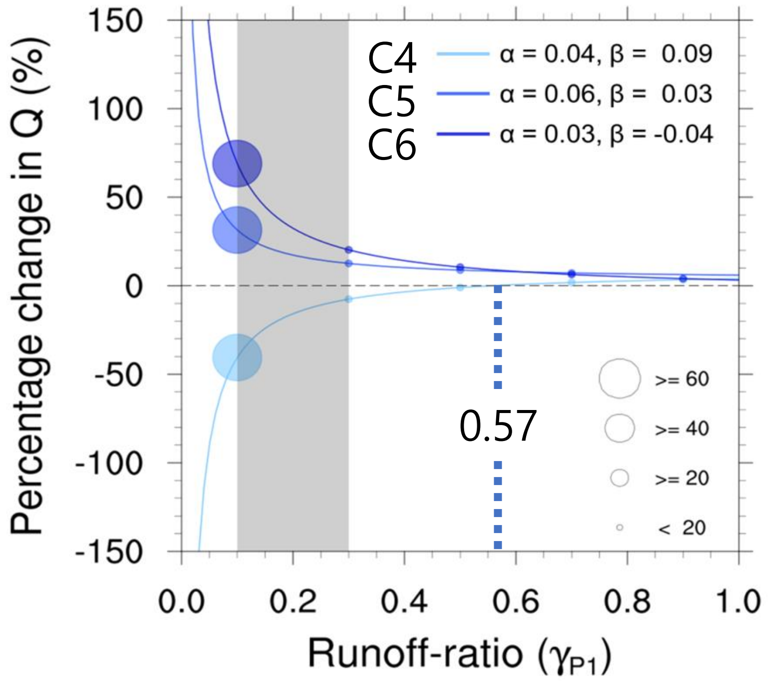
C1-C6



C1-C3

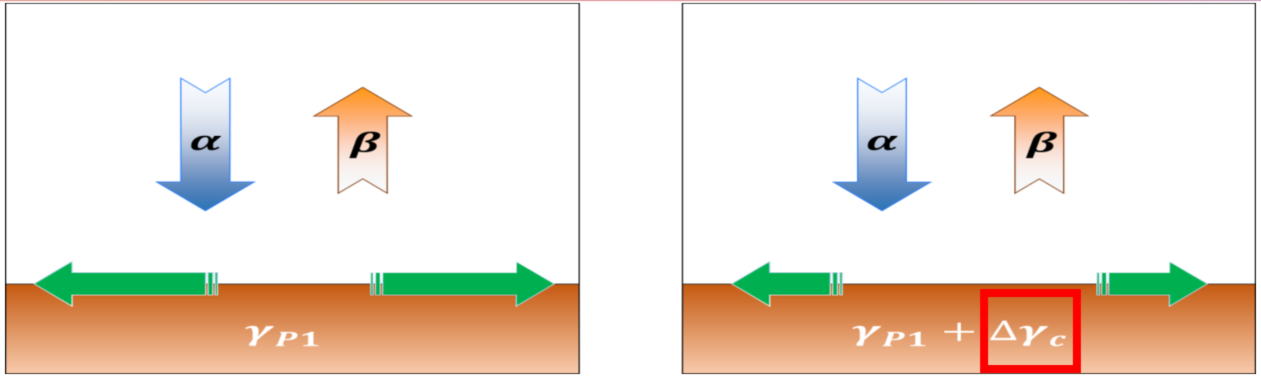


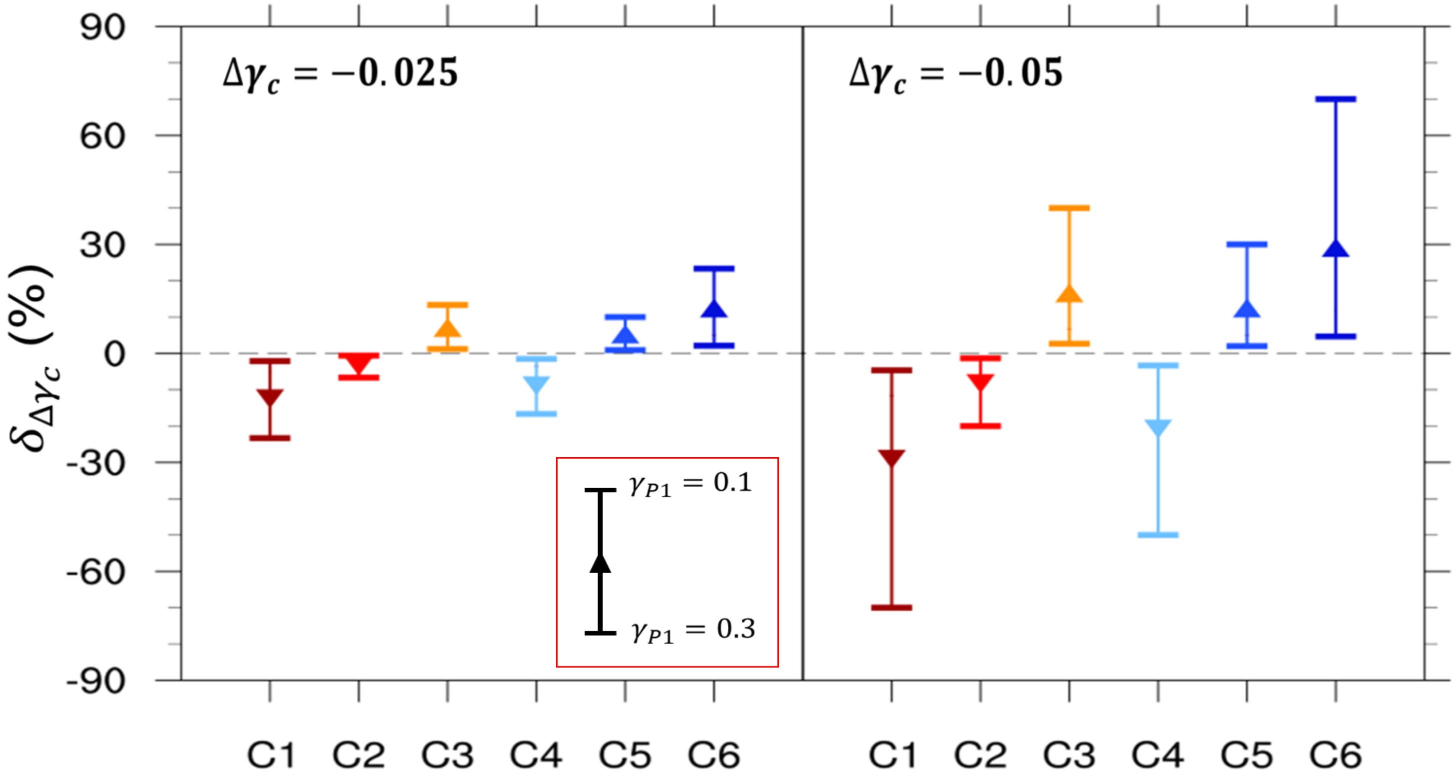
C4-C6



- Change in streamflow is very sensitive to climate change in regions with low runoff ratios.
- In cases 3 and 4 ($|\alpha| < |\beta|$), a sign of streamflow change is opposite to that of precipitation change when the runoff ratio is less than 0.57.
- In regions with a low runoff ratio, streamflow is more sensitive to change in evaporation than change in precipitation when the rate of change in evaporation is greater than the rate of change in precipitation.

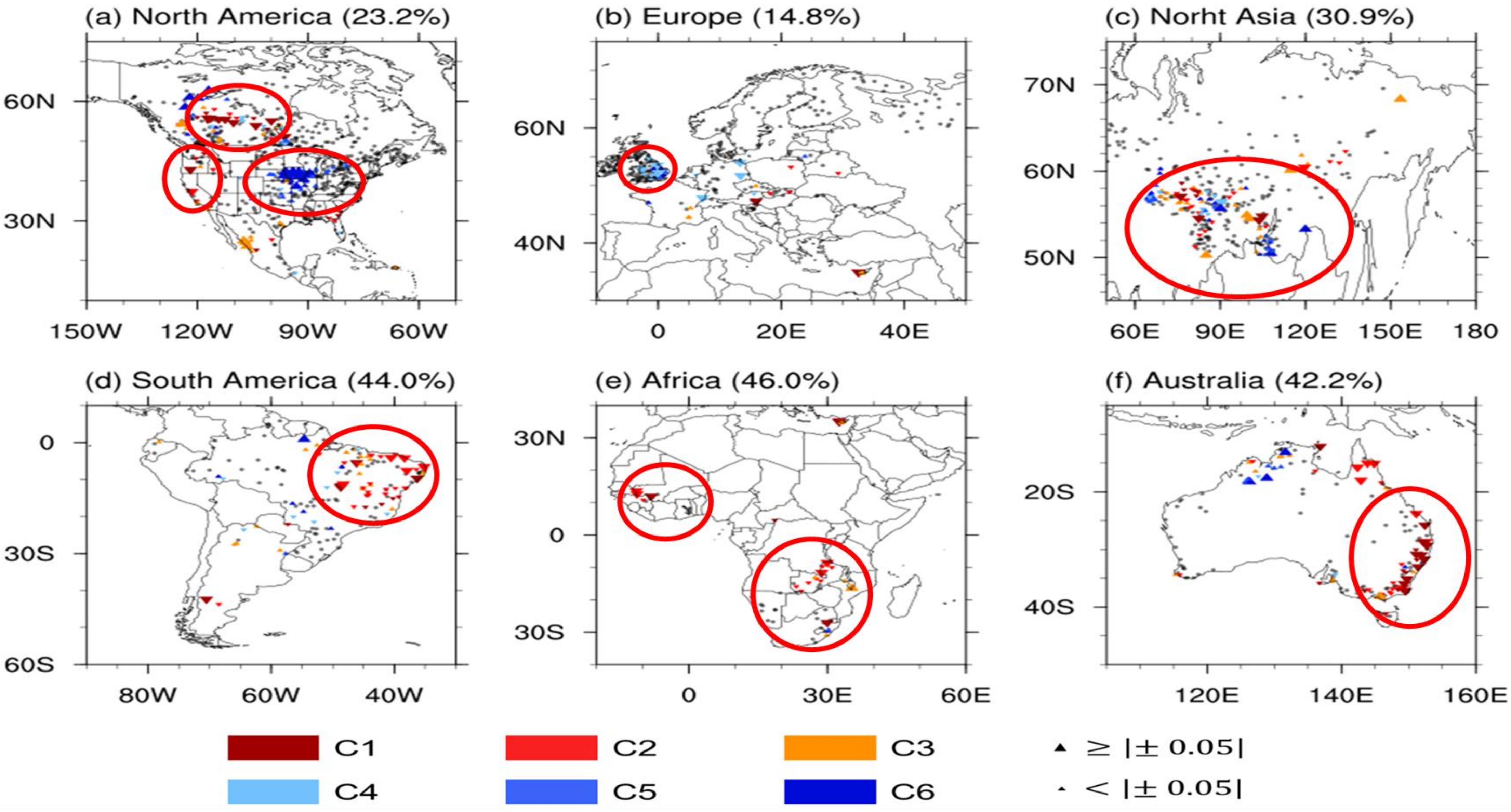
Range of change in streamflow by the decreased runoff ratio





- In all climate change cases, the greater reduction of runoff ratio can lead to a greater change of streamflow.
- The runoff ratio decreased by 0.025 (0.05) in the 0.1 than in the 0.3, the range of percentage change in streamflow increases by about 5 (17) times.
- The reduction of runoff ratio can lead the strengthened sensitivity of streamflow to climate change, especially in the low runoff ratio.

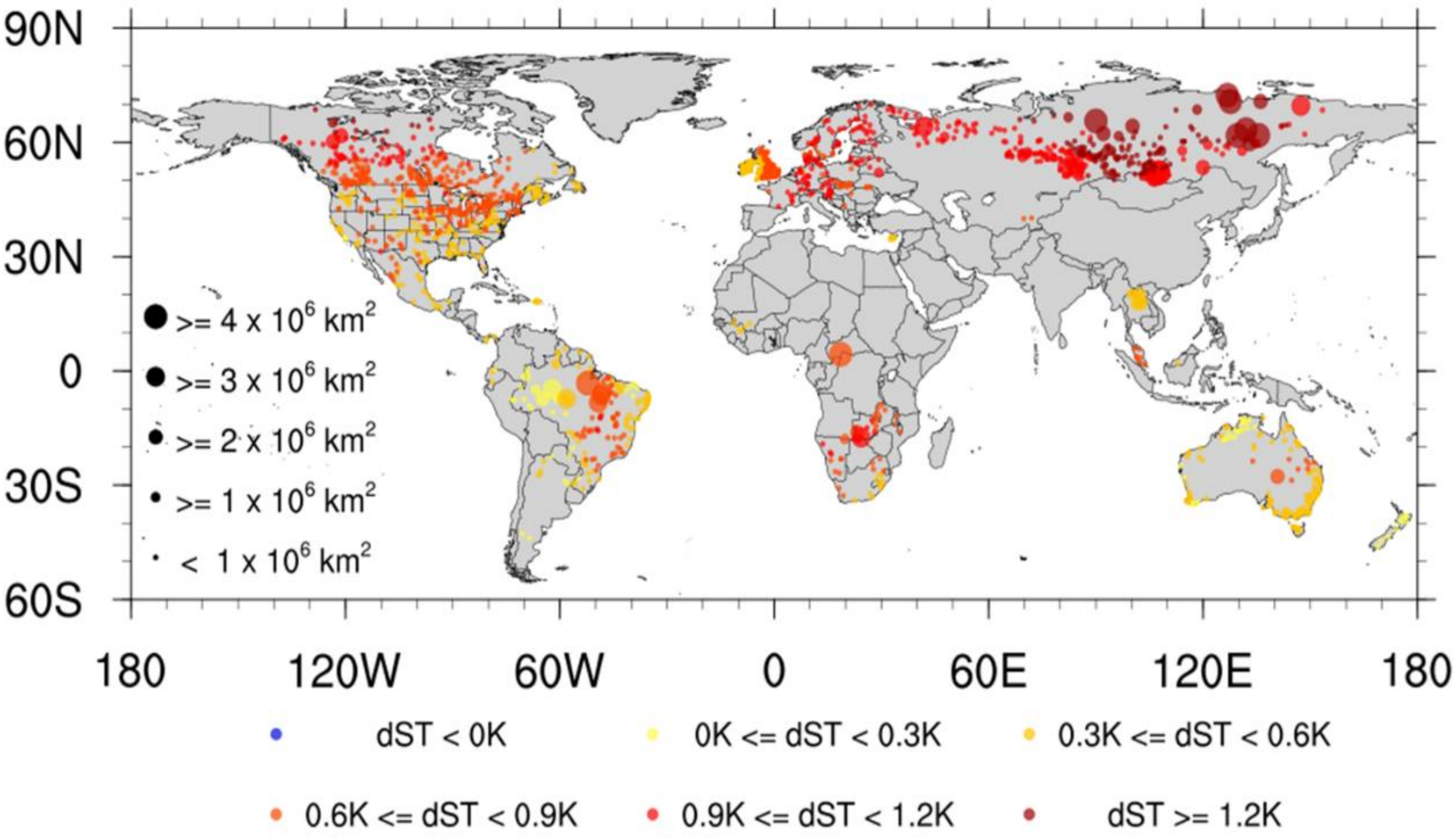
Vulnerable areas to climate changedue to the runoff ratio change

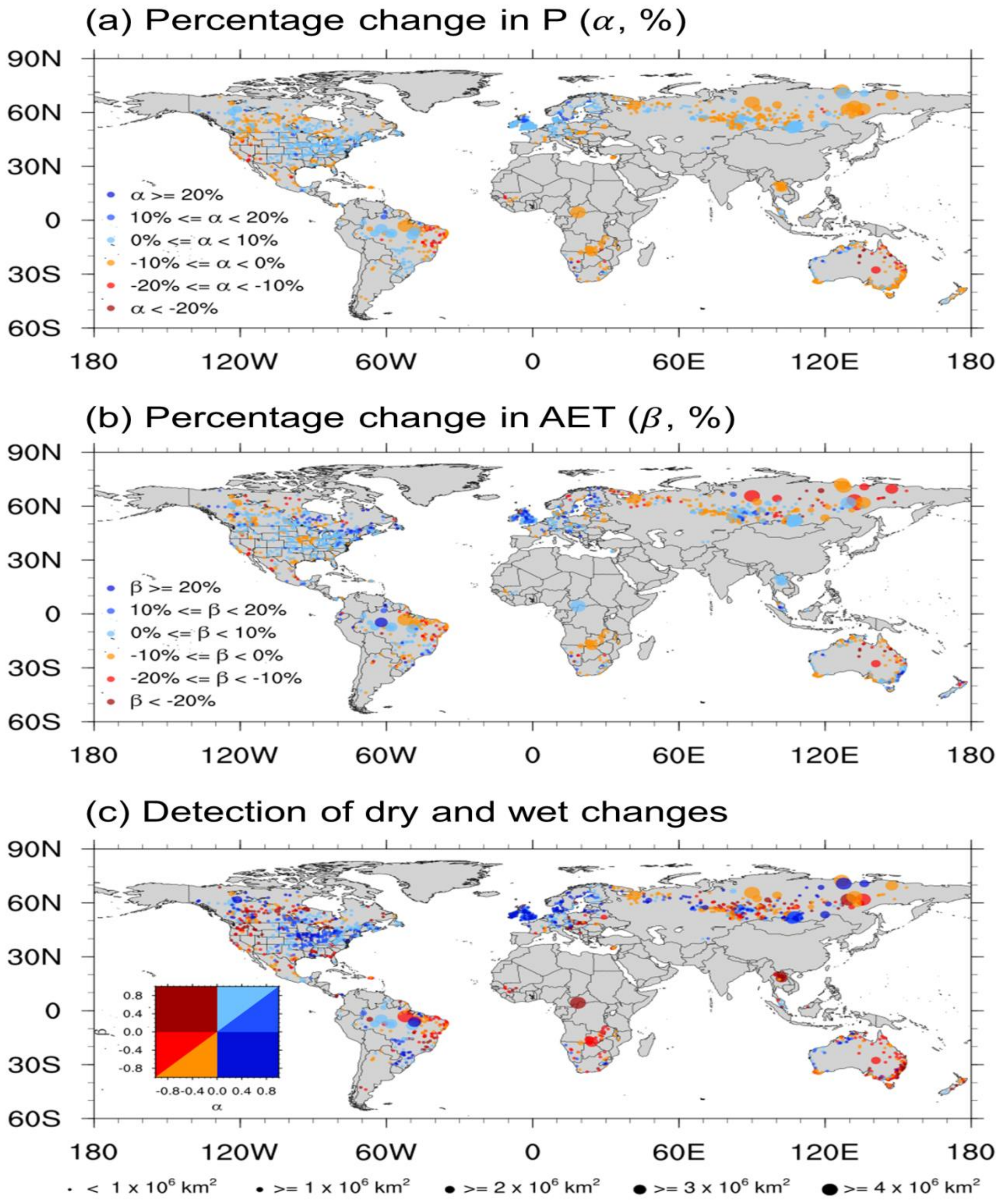


Summary

- In about 36.9% of 1,636 gage stations, climate change, in which the increase of evapotranspiration is greater than that of precipitation, prevails, and it is evident in the regions with runoff ratio of 0.2 to 0.6
- In most gage stations, streamflow is sensitive to changes in precipitation. However, in cases 3 and 4, which are the rate of evapotranspiration change is larger than that of precipitation change, the change in streamflow can be opposite to that in precipitation depending on the runoff ratio.
- Reductions in runoff ratio due to climatic or anthropogenic factors can amplify the impact of climate change on disasters such as drought and flood events, especially in regions with low runoff ratios.
- The western US, southwestern Canada, eastern Brazil, western and southern Africa, and eastern Australia could experience extreme drought due to a decrease in precipitation with a decrease in the runoff ratio.

Thank you for your attention


90N
60N
30N
0
30S
60S
180
120W
60W
0
60E
120E
180
>= 4 x 10^6 km^2
>= 3 x 10^6 km^2
>= 2 x 10^6 km^2
>= 1 x 10^6 km^2
< 1 x 10^6 km^2
dST < 0K
0K <= dST < 0.3K
0.3K <= dST < 0.6K
0.6K <= dST < 0.9K
0.9K <= dST < 1.2K
dST >= 1.2K



(a) Percentage change in P (α, %)
90N
60N
30N
0
30S
60S
180
120W
60W
0
60E
120E
180
α >= 20%
10% <= α < 20%
0% <= α < 10%
-10% <= α < 0%
-20% <= α < -10%
α < -20%
(b) Percentage change in AET (β, %)
β >= 20%
10% <= β < 20%
0% <= β < 10%
-10% <= β < 0%
-20% <= β < -10%
β < -20%
(c) Detection of dry and wet changes
0.8
0.4
0.0
-0.4
-0.8
-0.8 -0.4 0.0 0.4 0.8
α
< 1 x 10^6 km^2
>= 1 x 10^6 km^2
>= 2 x 10^6 km^2
>= 3 x 10^6 km^2
>= 4 x 10^6 km^2