Comparative hydrology to elucidate the role of snowiness on the mean streamflow of catchments

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Introduction

In a **warming climate**, precipitation is increasingly likely to be rain instead of snow. A shift from a snow regime towards a rain regime leads to changes in the within-year distribution of streamflow, but **consequences for the mean streamflow are generally assumed to be negligible**[1]. However, there is little evidence regarding this assumption.

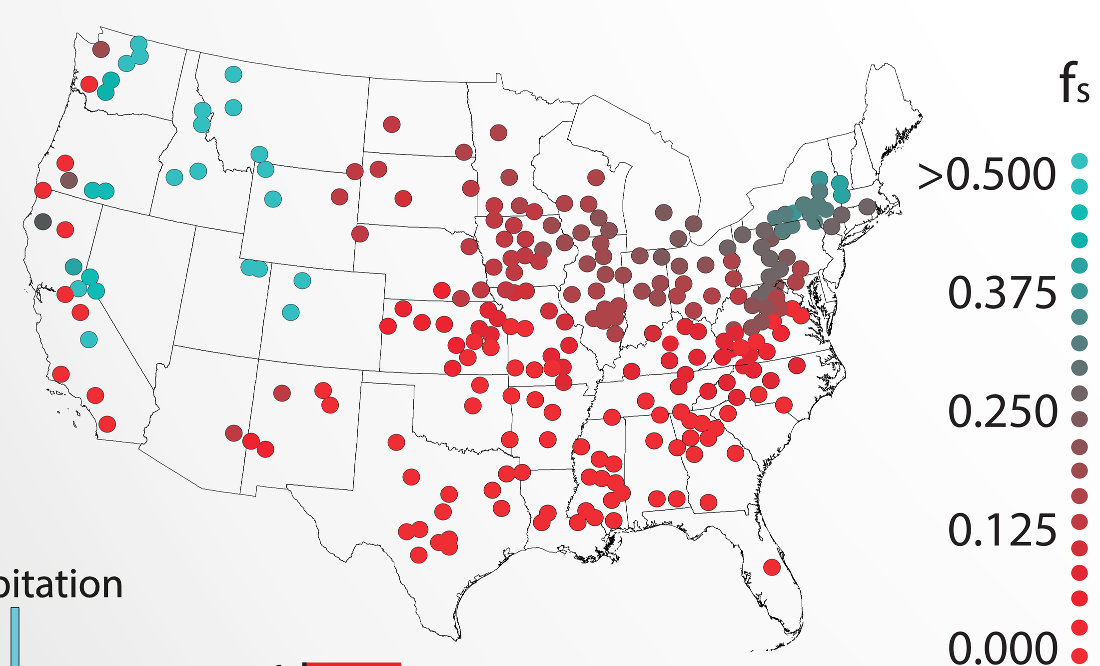
Research question

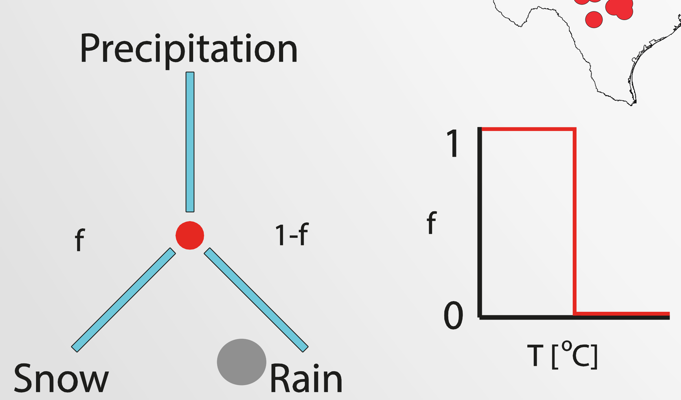
Is the mean streamflow of a catchment significantly affected by snowiness?

Study sites and data

Data are from the **MOPEX** dataset which consists of **420 catchments located across the United States**[2] hosting a wide diversity of landscape and climate characteristics.

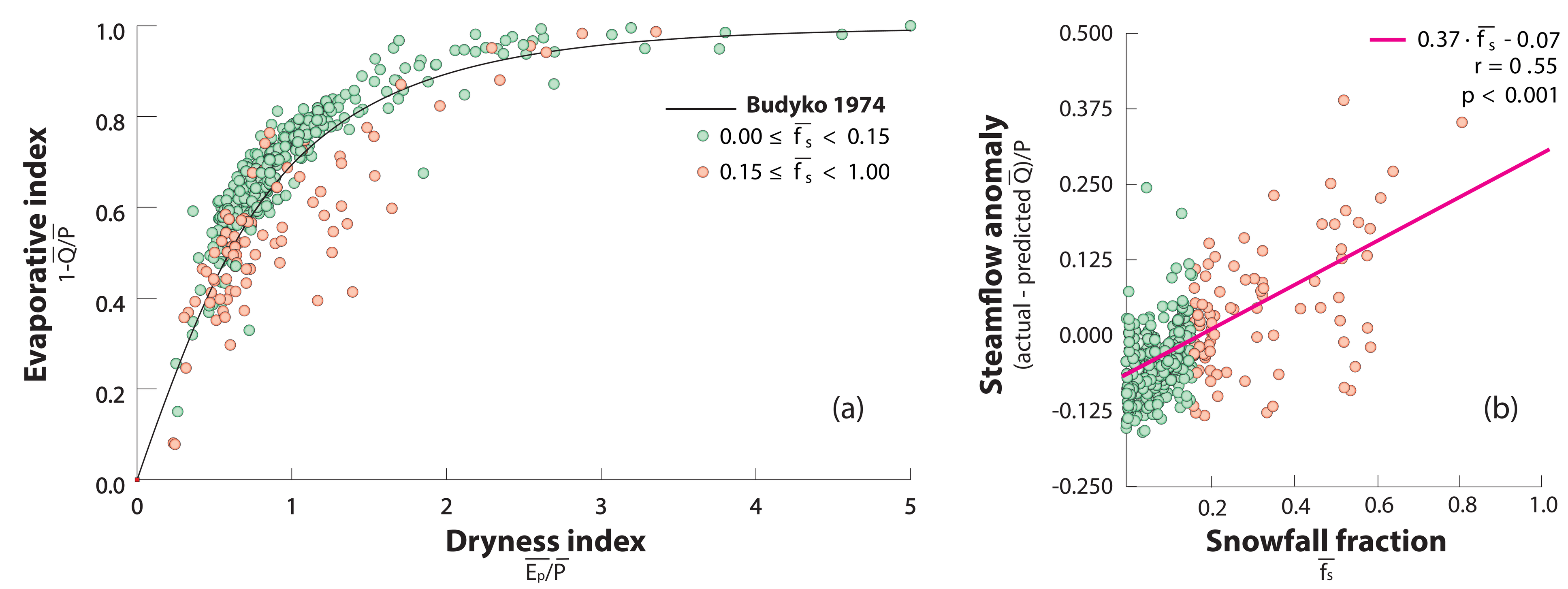
The fraction of precipitation falling as snow (f_s) is approximated using a simple **temperature threshold** on each day of recorded data. Precipitation measurements are corrected for mean monthly **undercatch**[3].





What is the effect of snowiness for on long-term streamflow?

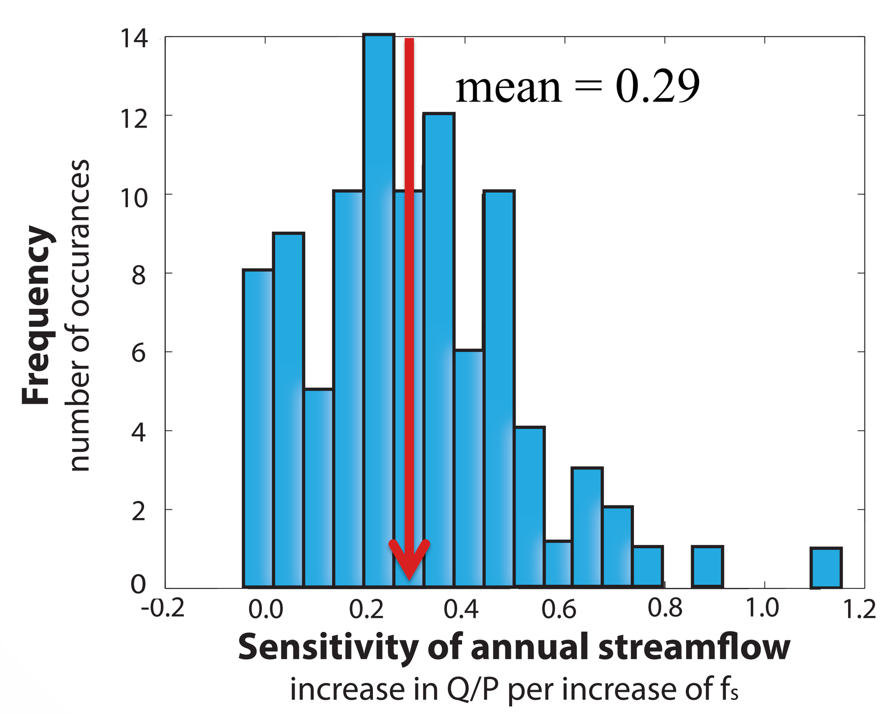
Measurements of the catchments are put in context of the Budyko curve[4].



Mean annual streamflow and streamflow anomaly in the context of the Budyko hypothesis, stratified by snow fraction. The observed long-term (16-54 years) streamflow and precipitation measurements are placed in context of the Budyko curve. Departures below the Budyko curve for catchments with a significant fraction of the precipitation falling as snow indicate that an increased fraction of precipitation as snowfall is associated with higher streamflow. **Catchments with more snow tend to have higher mean streamflow.**

What is the role of snowiness for the inter-annual streamflow?

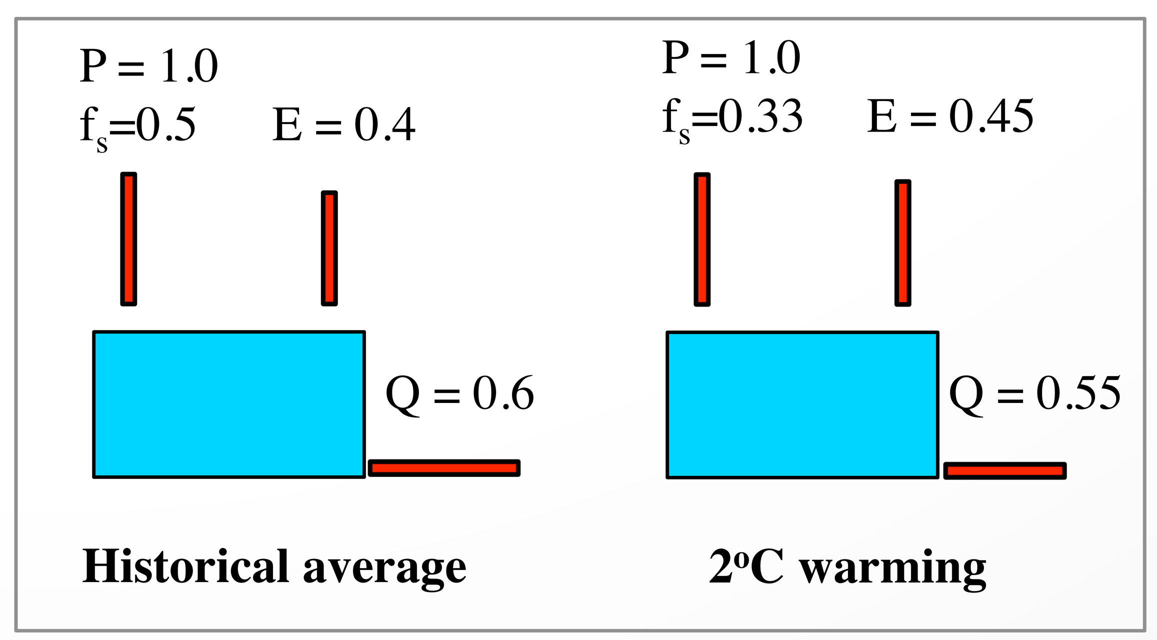
Since between-catchment differences in the water balance can be caused by many factors which are correlated with the long-term average snow fraction (topography, land-cover, human activity etc.), we also study the inter-annual streamflow of catchments, using linear regression to estimate the annual streamflow variation due to variations in the snow fraction.



Sensitivity of annual streamflow to the fraction of annual precipitation falling as snowfall. The histogram displays the change in normalized streamflow (Q/P) per unit of change of the annual snow fraction (f_s) for 97 catchments with $f_s > 0.15$. Values indicate that the annual streamflow of catchments varies (between years) according to the annual f_s. **Years with higher snow fraction, f_s, tend to have higher values of annual streamflow.**

Are effects of warming significant?

For the U.S. MOPEX data, a **2ºC temperature rise** leads to **35% decrease in f_s**, on average. The average change in normalized streamflow is 0.29 per unit of f_s. This would imply that a 2ºC temperature rise on average leads to decreases in normalized streamflow (Q/P) of the order of 0.10 times the historical f_s (assuming no confounding effects). Thus, **streamflow can be significantly impacted by a temperature rise.**



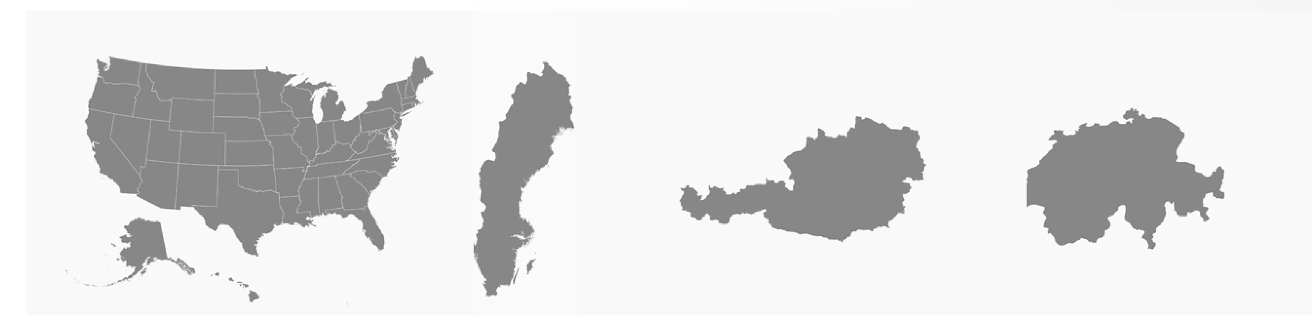
Summary and Conclusion

- Catchments with higher snowiness (f_s) tend to have more streamflow.
- Years with higher snowiness (f_s) tend to have higher values of annual streamflow
- Streamflow can be significantly impacted by a 2ºC temperature rise.

A precipitation shift from snow towards rain decreases the mean streamflow[4]. This finding can have implications for regional water resources, but also challenges our understanding of snow-affected regions.

Future Work

- Do we observe similar behavior in other catchments and regions?



- What parts of the streamflow regime are affected by the snow-rain partitioning?
  - Mean water balance
  - Inter-annual water balance
  - Seasonal regimes
  - Flow duration curve
  - Baseflow index
  - Etc.
- To what degree can this behavior be reproduced by the current generation of hydrological models?

References

1. Barnett *et al.* Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature 438, 303 (2005).*
2. Schaake *et al*. The US MOPEX data set. *IAHS publication* (2006)
3. Groisman & Legates (1994), The accuracy of United States precipitation data, Bull. Am. Meteorol. Soc., 75, 215 – 227.
4. Budyko. Climate and life (Academic Press, New York 1974)
5. Berghuijs, Woods & Hrachowitz. A precipitation shift from snow towards rain leads to a decrease in streamflow, *Nature Climate Change* (2014) doi:10.1038/nclimate2246