Decoupling of mountain snowpacks from hydrology in a warmer climate

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Temperature warming is the most certain consequence of human emissions of greenhouse gases

"The largest changes in the hydrological cycle due to warming are predicted for the snow-dominated basins of mid- to higher latitudes, because adding or removing snow cover fundamentally changes the snow pack's ability to act as a reservoir for water storage" (Barnett et al. 2005)

TEMPERATURE INCREASE → LESS SNOW → ALTERED RIVER REGIMES
REDUCED SPRING FRESHEET

but

It has been observed that snowpack and hydrology respond very differently to warmer temperatures in different parts of the world.

The links between snow regime and hydrological sensitivity to temperature warming are not well understood yet.

Snowpack sensitivity to global warming

PNAS

Humidity determines snowpack ablation under a warming climate

Adrian A. Harpold[a,b,1] and Paul D. Brooks[c]

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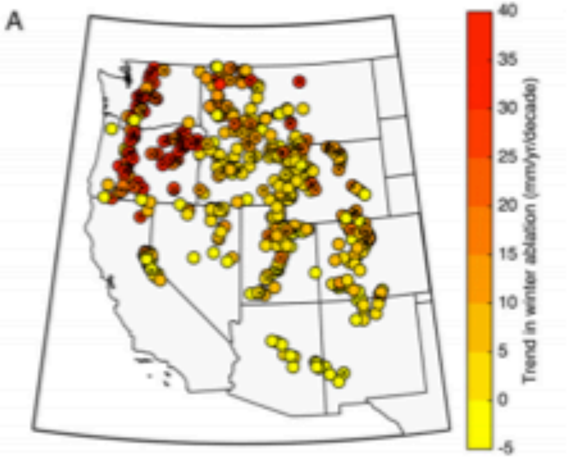
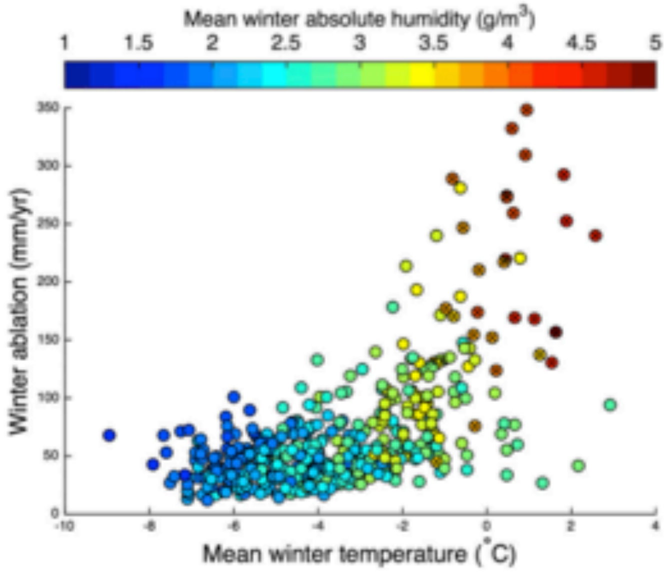
Climate change is altering historical patterns of snow accumula- ... observations with mechanistic understanding of snowpack mass



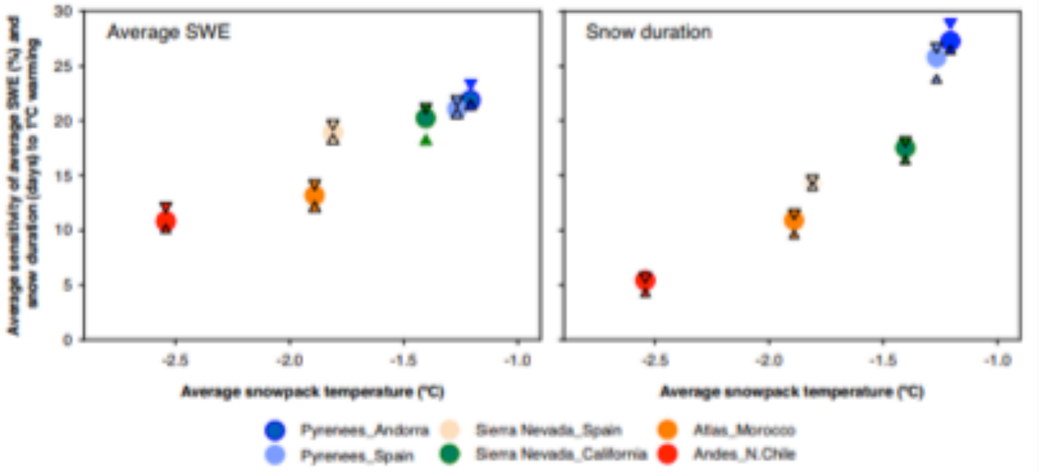


Environmental Research Letters

LETTER

Different sensitivities of snowpacks to warming in Mediterranean climate mountain areas

J I López-Moreno[1,13], S Gascoin[2], J Herrero[3], E A Sproles[4], M Pons[5], E Alonso-González
A Boudhar[7], K N Musselman[8], N P Molotch[9,10], J Sickman[11] and J Pomeroy[12]



Snowpack and hydrological sensitivity to global warming

Difficulties:

–**Difficult to relate observed changes in snowpack with temperature because** other meteorological (radiation, relative humidity, etc), topographical (elevatio, slope, aspect) and environmental (vegetation cover, presence of water, etc) infer the temporal evolution of snowpack.

– **Need to work with physicalled based SEB** models and conduct sensitivity analyses

- Few observations (and normally short and incomplete series) to run SEB (automathic weather stations). Analyses cannot be conducted in many mountainous areas of the world.

– **Even more complicated for hydrological sensitivity**: Many factors affect the hydrological response and they difficult disentangling the role of temperature

Snowpack and hydrological sensitivity to global warming

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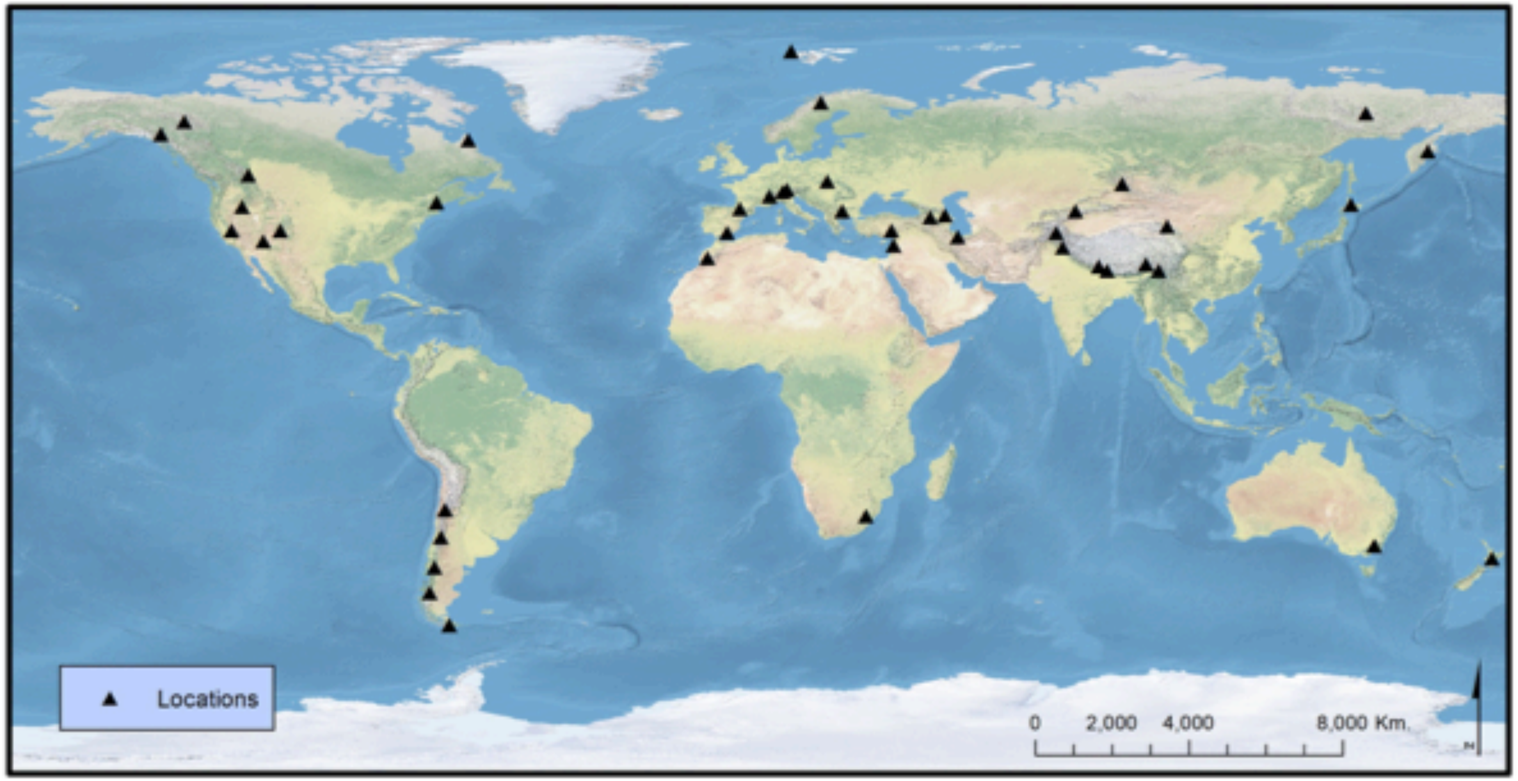
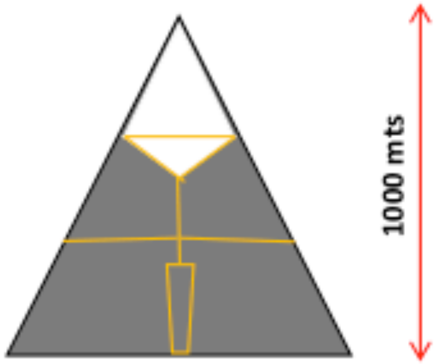
SOLUTION: VIRTUAL BASIN + REANALISIS DATA

44 VIRTUAL BASINS



7 HRUs
1: Summit
2 High elevation plateau
3: Upper North
4: Upper South
5: Lower North
6: Lower South
7: Bottom



Little role of vegetation with bare terrain at the higher HRUs and grasslands at the lower elevations

No groundwater recharge and limited soild water storage retention (thin soils at higher HRUs and no more than 1 meter at the lower elevations)

Elevation of the basin to ensure the existence of seasonal snowpack but avoiding formation of glaciers

REANALYSIS AS INPUT data

1. Bias corrected ERA-40 Reanalysis

Temperature	
Precipitation	Bias corrected ERA-40 Reanalysis
Incoming solar radiation	0.5º spatial resolution
Air pressure	3 hours time step
Wind speed	1980-2012
Air humidity	

2. Download data of the pixel containing the coordinates of the target mountain area (INARCH sites or selected mountains in the world)

3. Using CRHM for scaling inputs from elevation of the WATCH data centroid to the elevation, slope and aspect of each HRU of the virtual basin

4. Using CRHM for simulating snow water equivalent, energy balance components and the basin runoff output

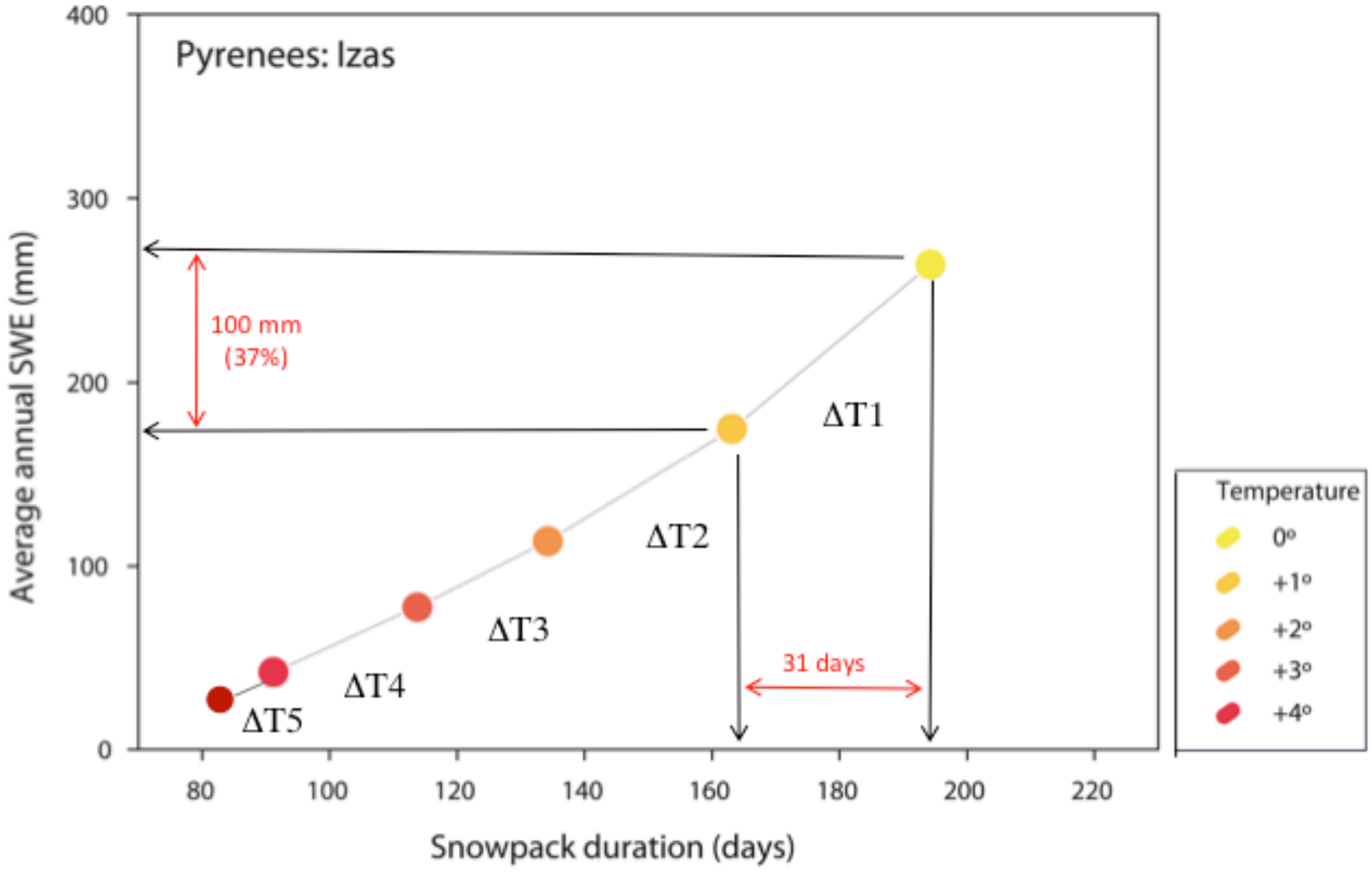
The aim is not having data that reproduces exactly the conditions of each point, but to ensure we are using coherent inputs gathering much of the climates found in snow dominated basins in the world

Sensitivity analysis

Run of CRHM simulations at each virtual basin for **control** conditions and **T+1ºC, T+2ºC, T+3ºC, T+4ºC, T+5ºC**

Propose indices to represent the snow and hydrological regimes

Sensitivity per ºC:
(ΔT1+ ΔT2+ ΔT3+ ΔT4+ ΔT5)/5



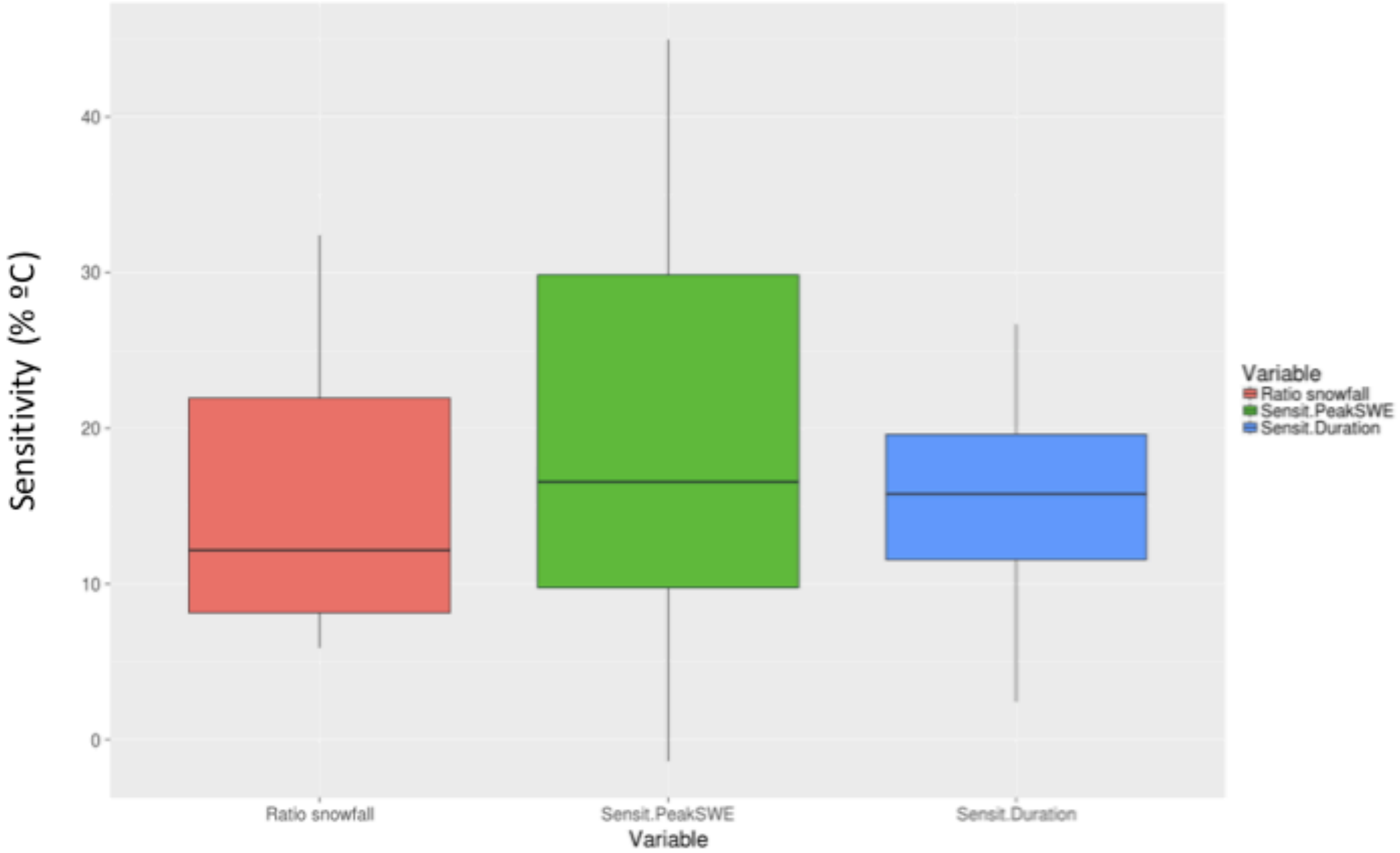
Questions

1- How sensitive are global mountain snow regimes and hydrology to changes in climate associated with increased air temperatures.

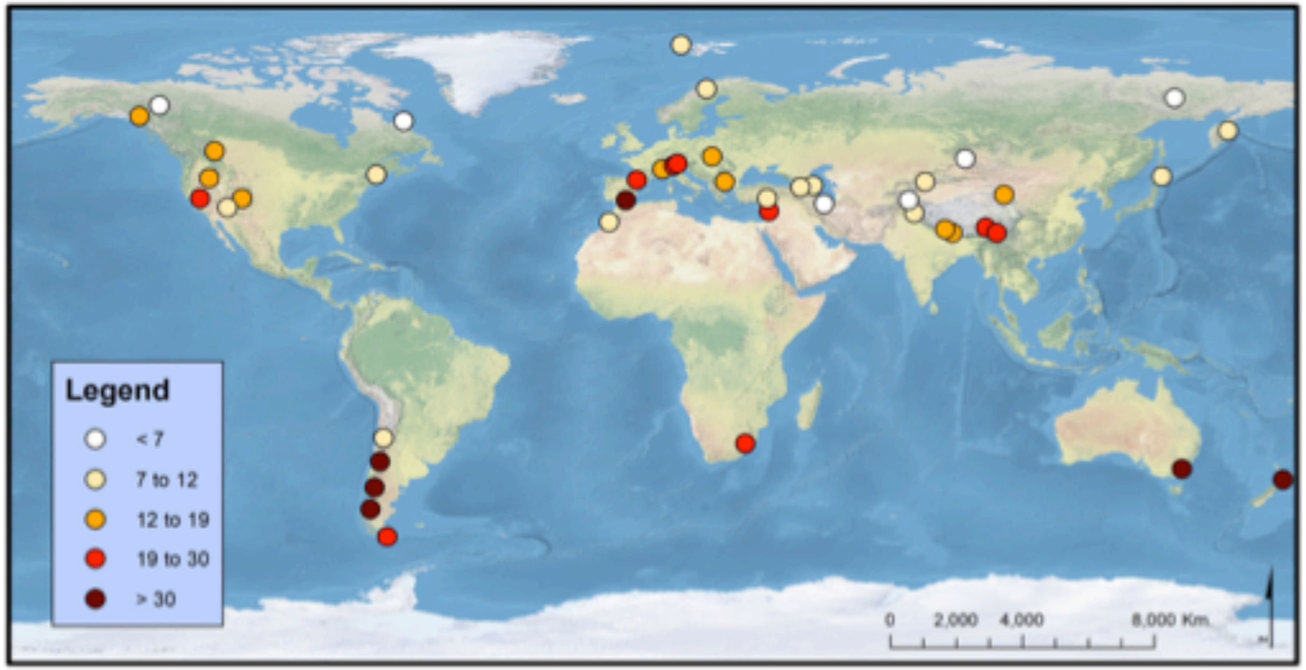
2- How do process interactions mediate sensitivity for snow regimes and for hydrology?

3- Will reduced snowpacks under global warming result in reduced streamflow generation?

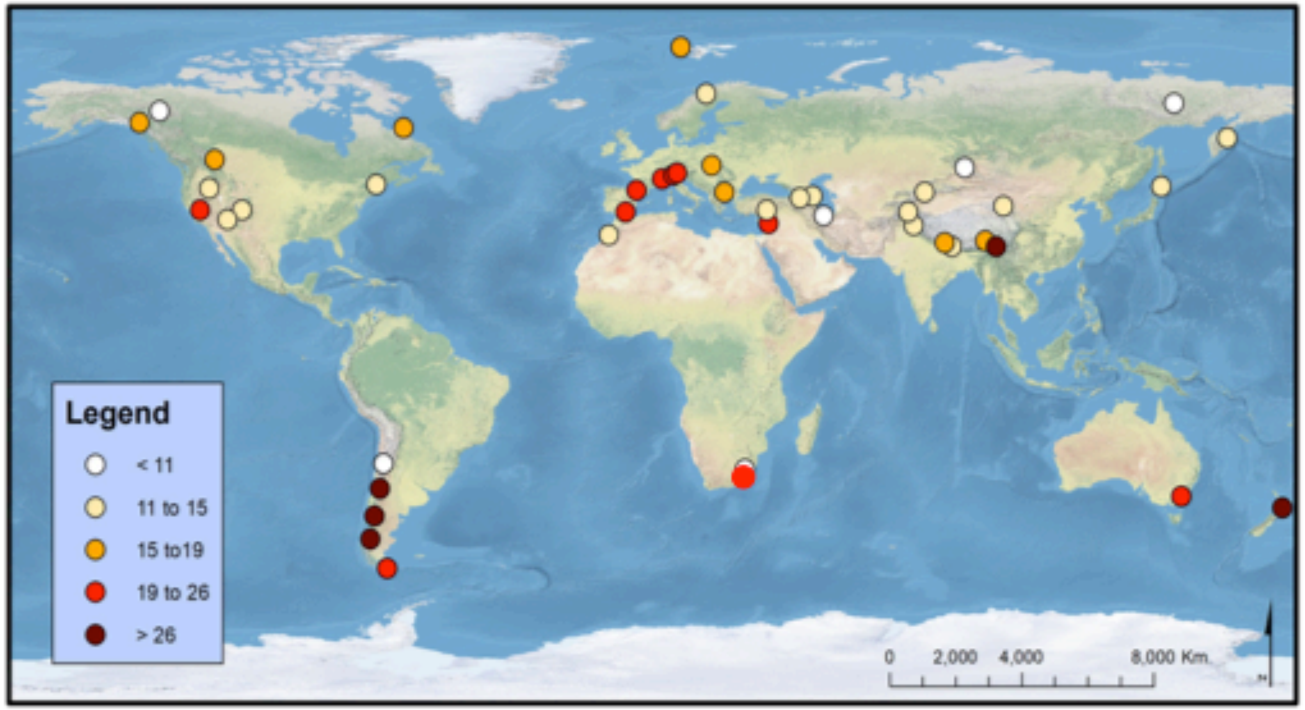
Sensitivity of snowpack



Sensitivity of snowpack

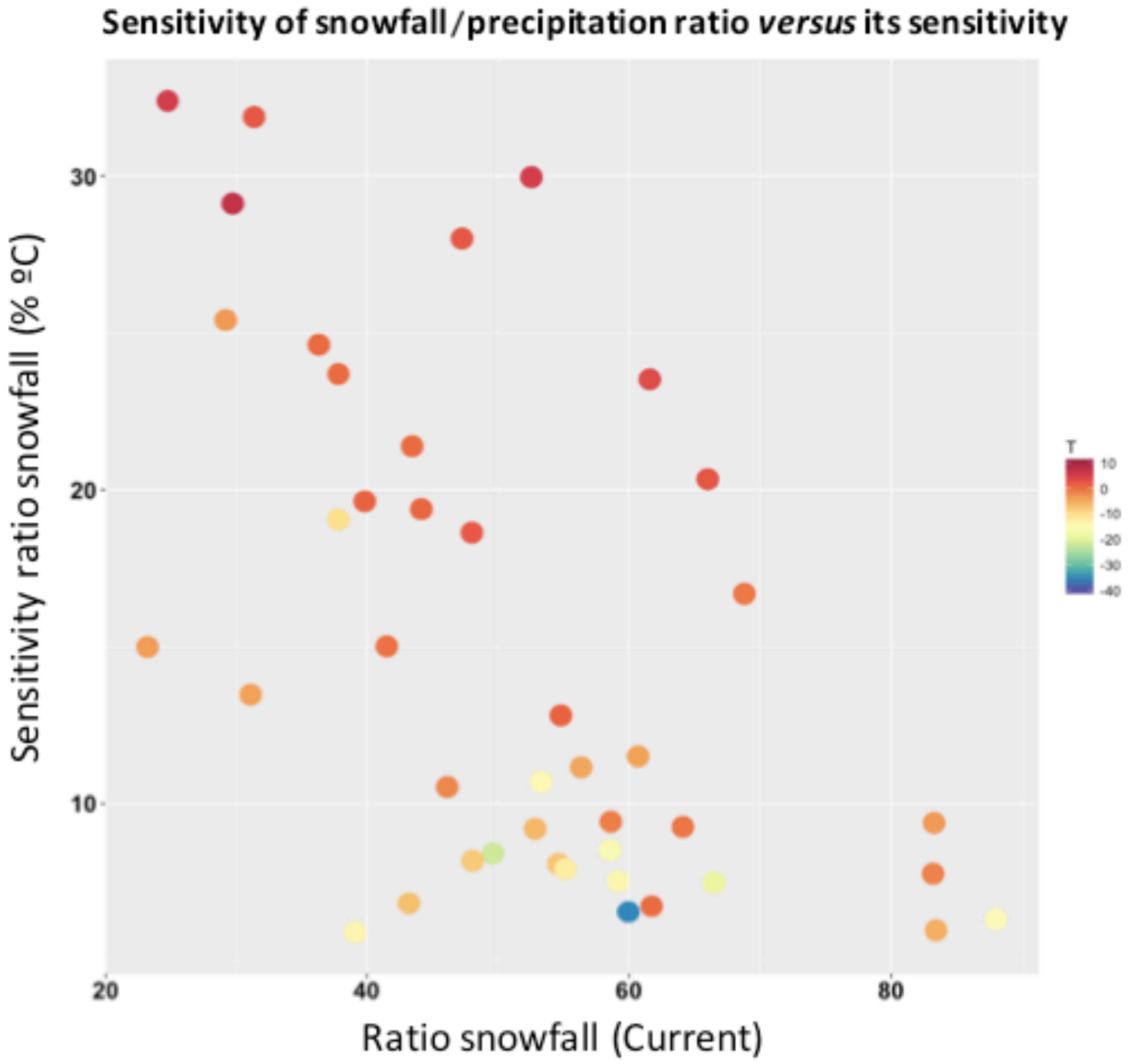


Sensitivity of Peak SWE

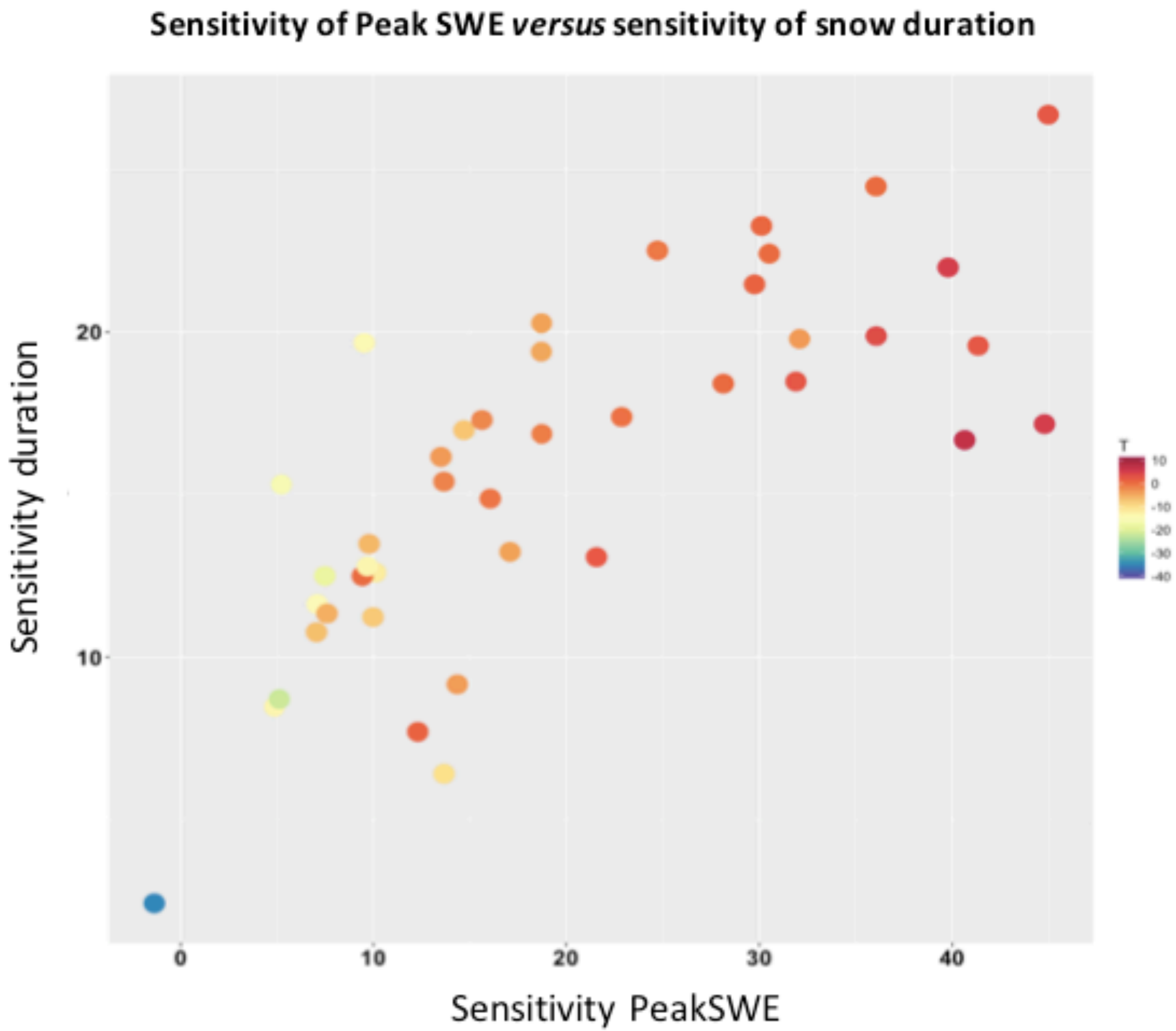


Sensitivity of snow duration

Sensitivity of snowpack

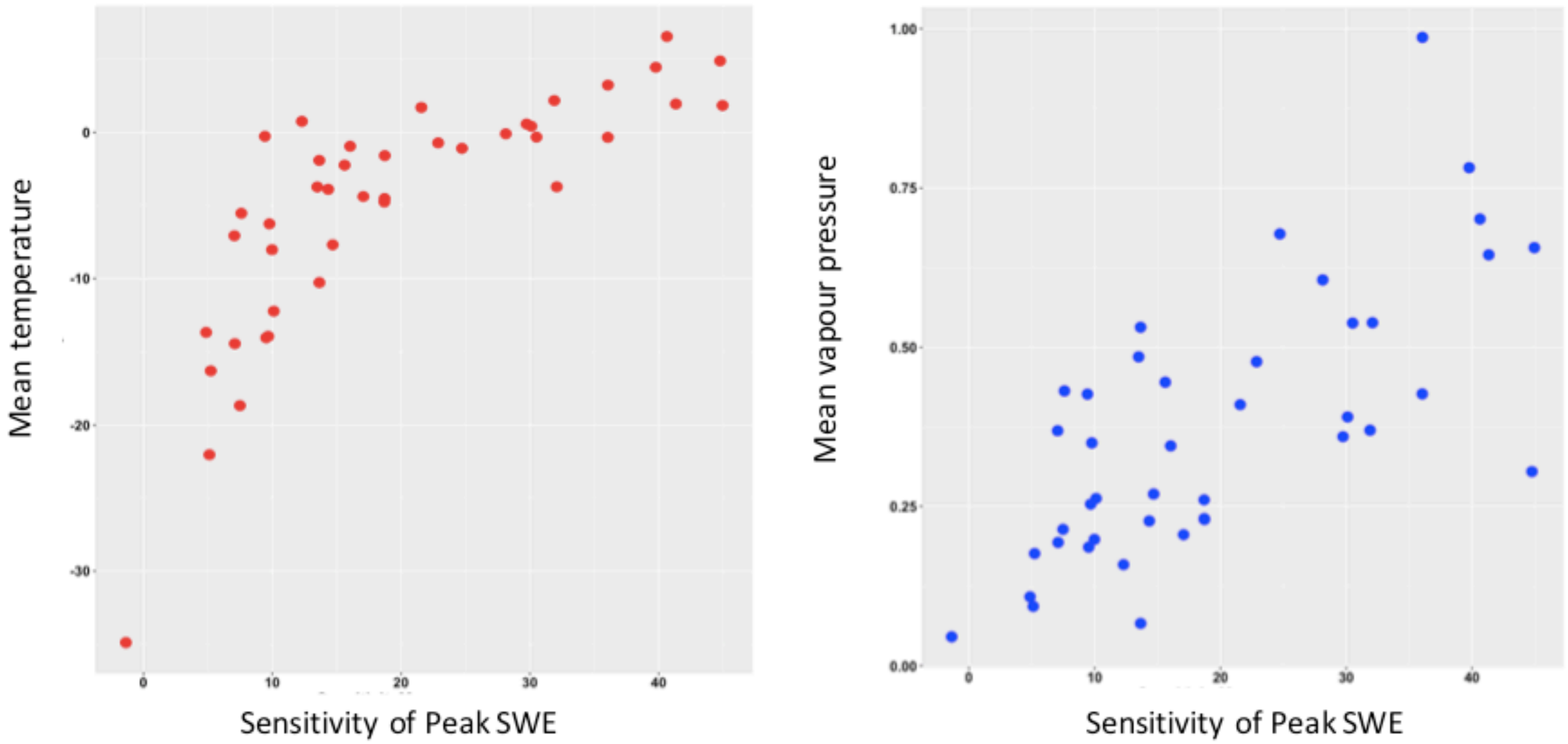


Sensitivity of snowpack



Sensitivity of snowpack

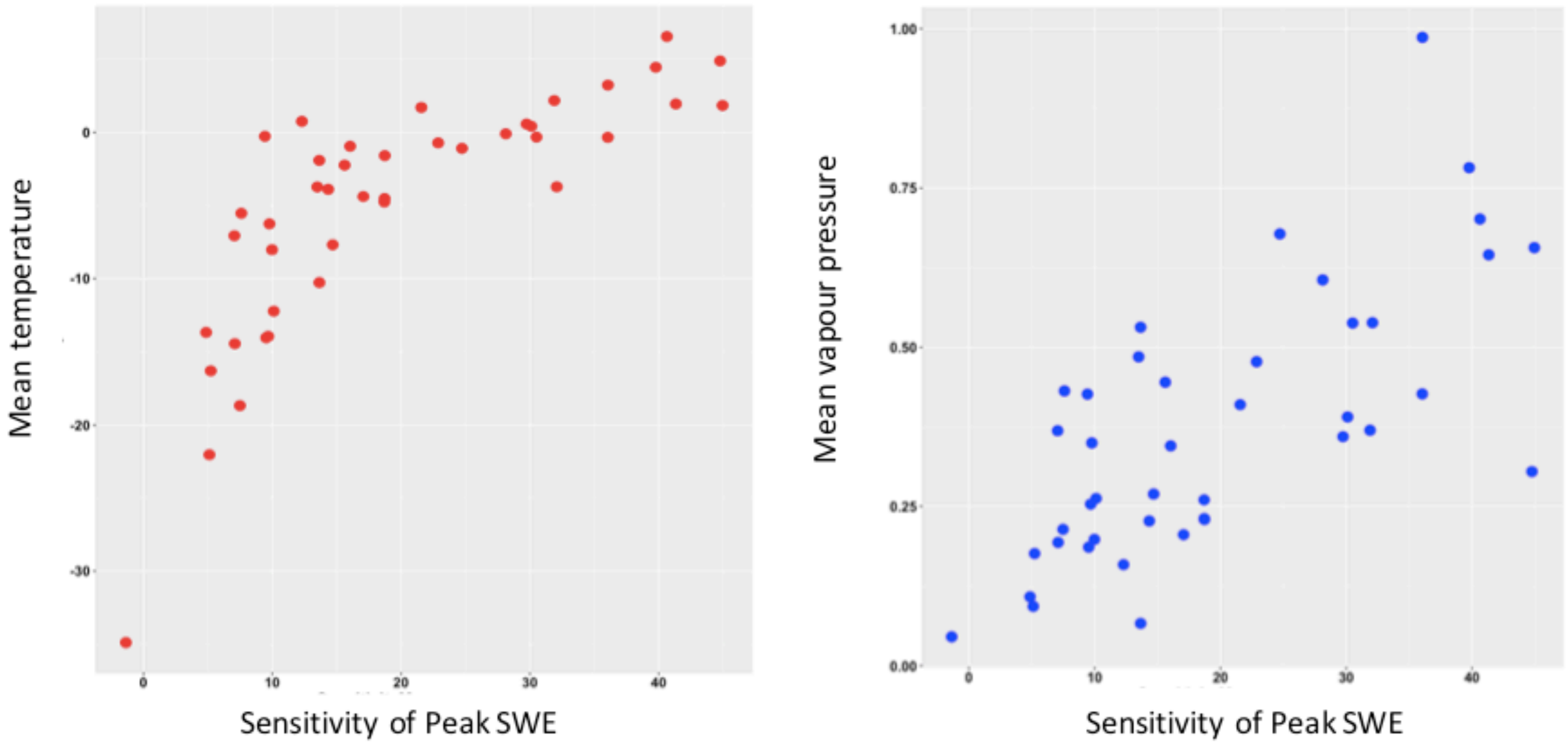
Sensitivity of Peak SWE *versus* temperature and vapour pressure



Sensitivity of snowpack

Linear regression model $r^2 = 0.81$

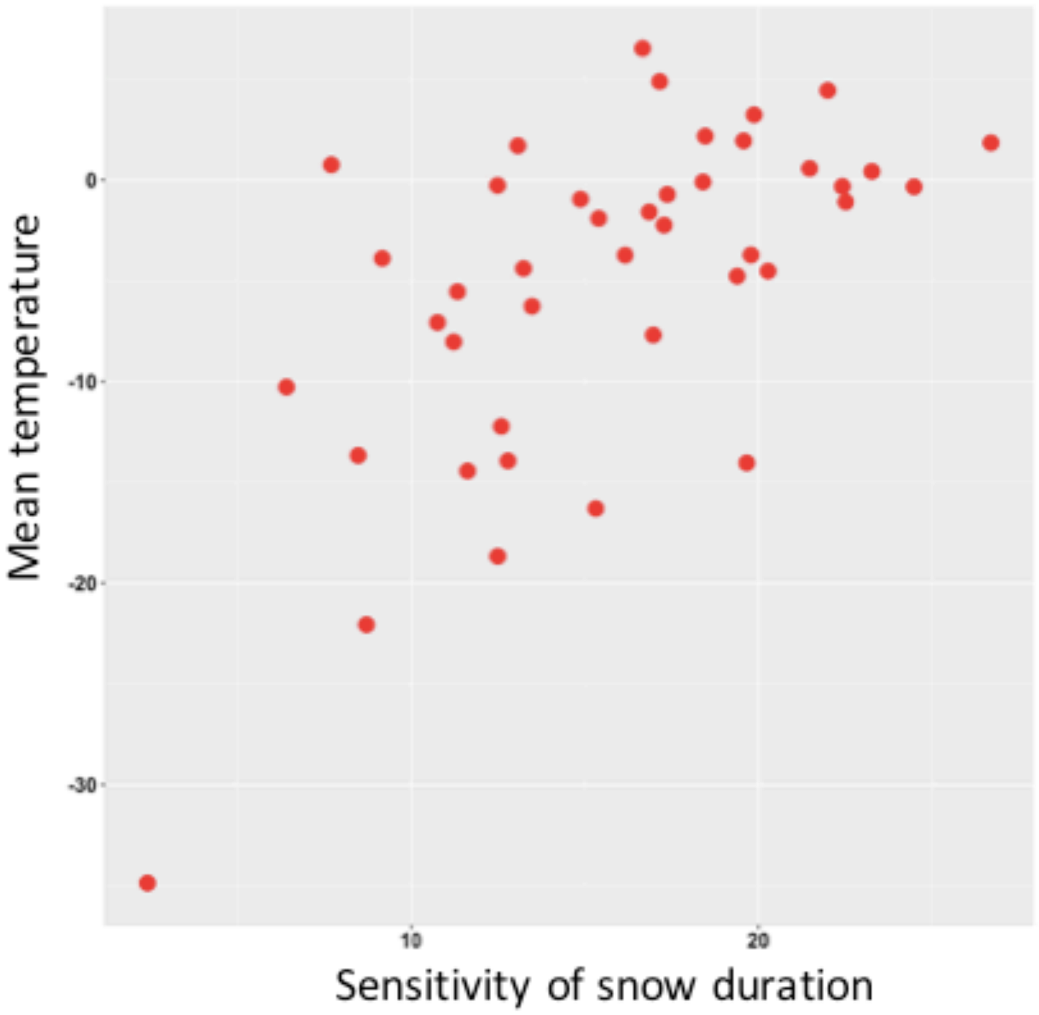
Sensitivity of Peak SWE *versus* temperature and vapour pressure

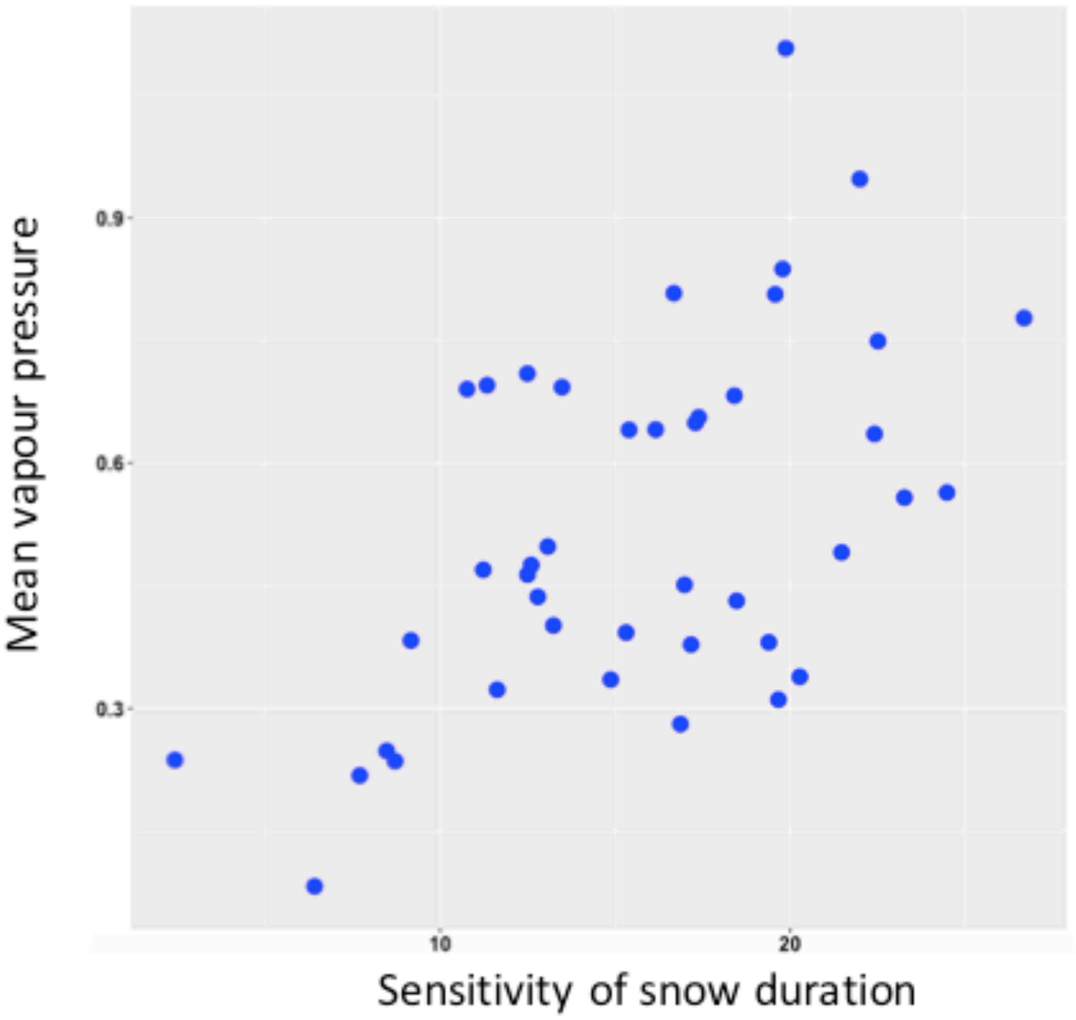


Sensitivity of snowpack

Linear regression model **r^2= 0.55**

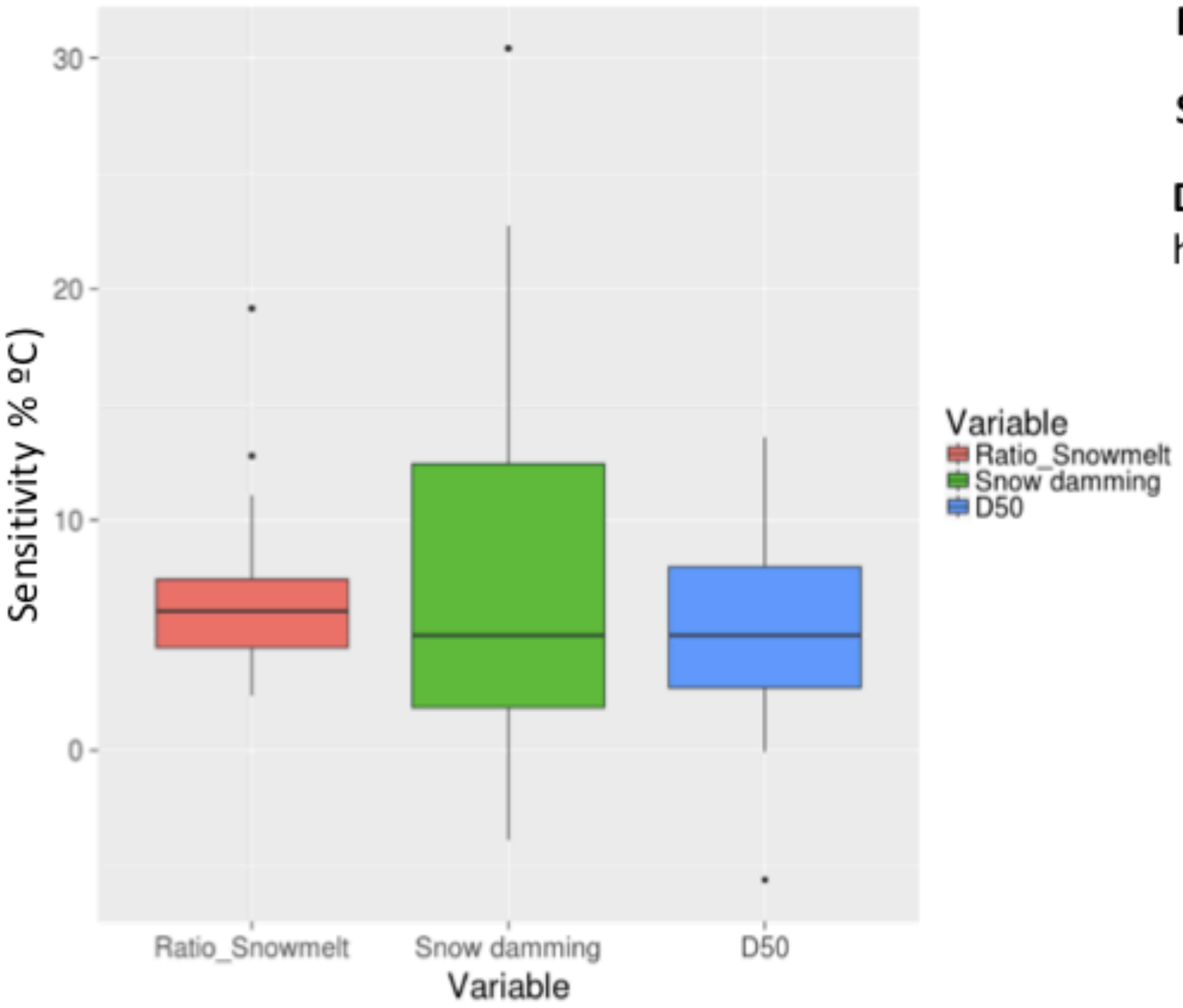
Sensitivity of snow duration *versus* temperature and vapour pressure





Hydrological sensitivity

Variability of sensitivity for 3 hydrological indices



Ratio Snowmelt: Ratio between snowmelt and annual Q

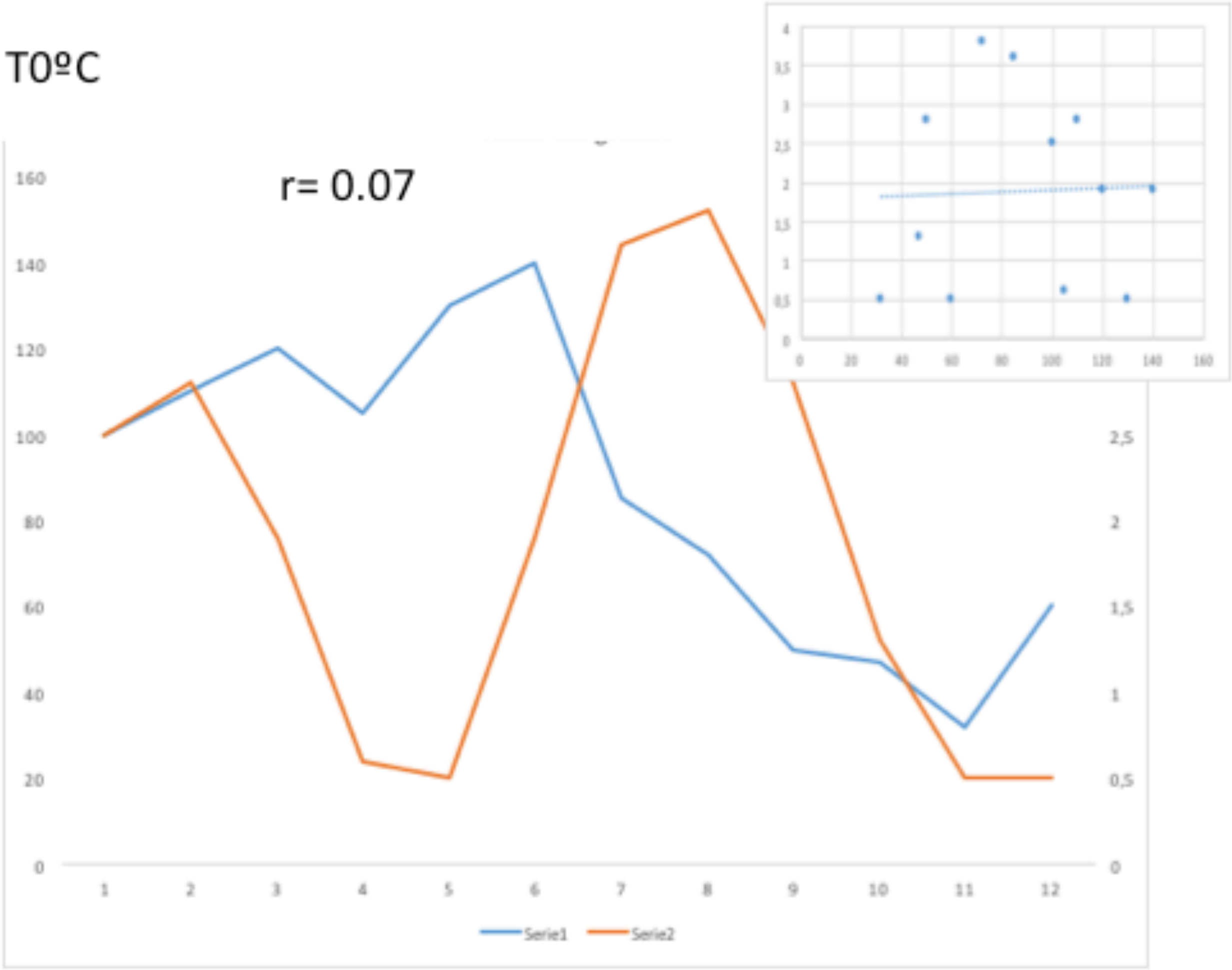
Snow damming: Change in r value between monthly P and Q

D50: Change in the day where the center of mass of the hydrograph occurs

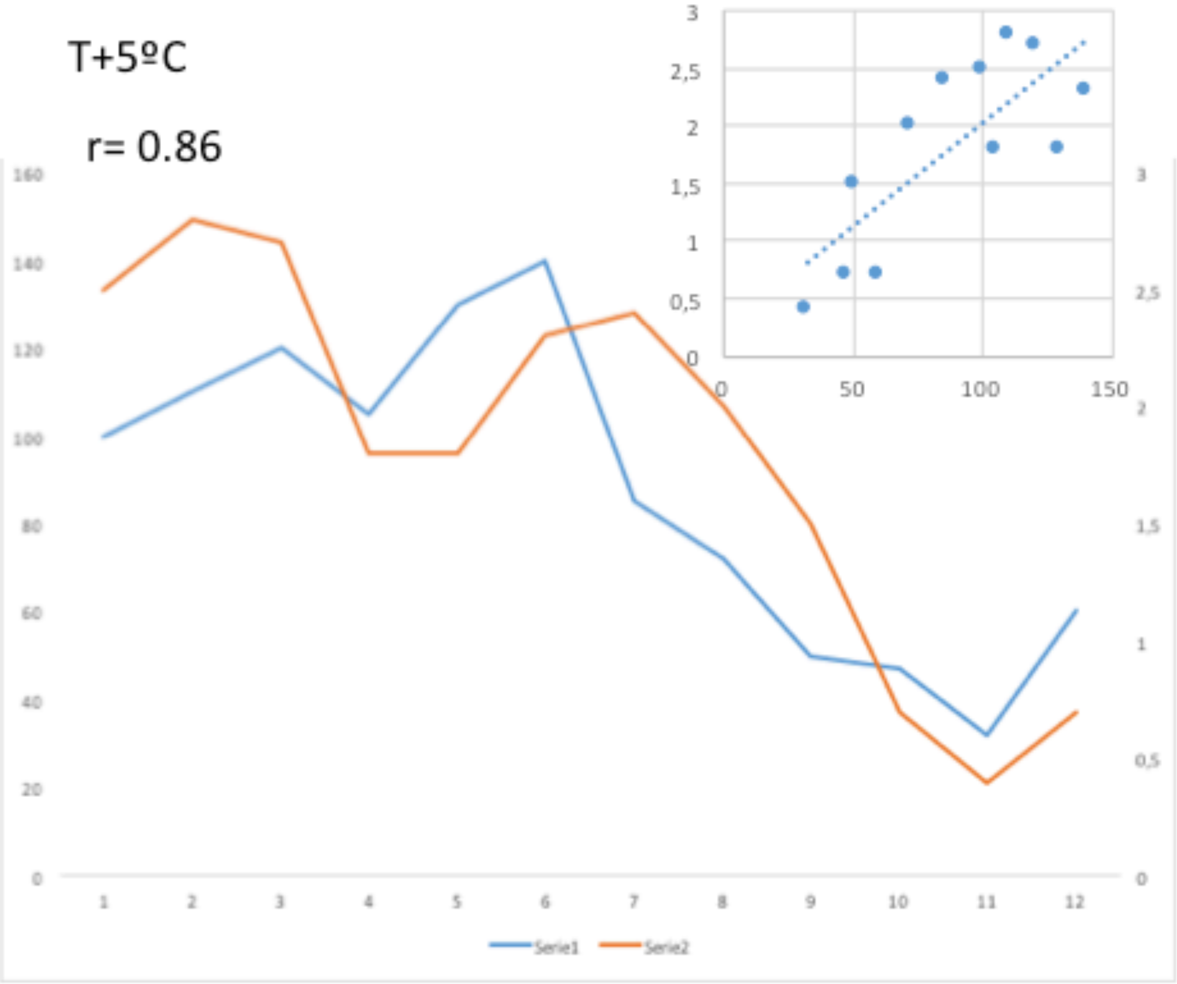
Hydrological sensitivity

Snow damming

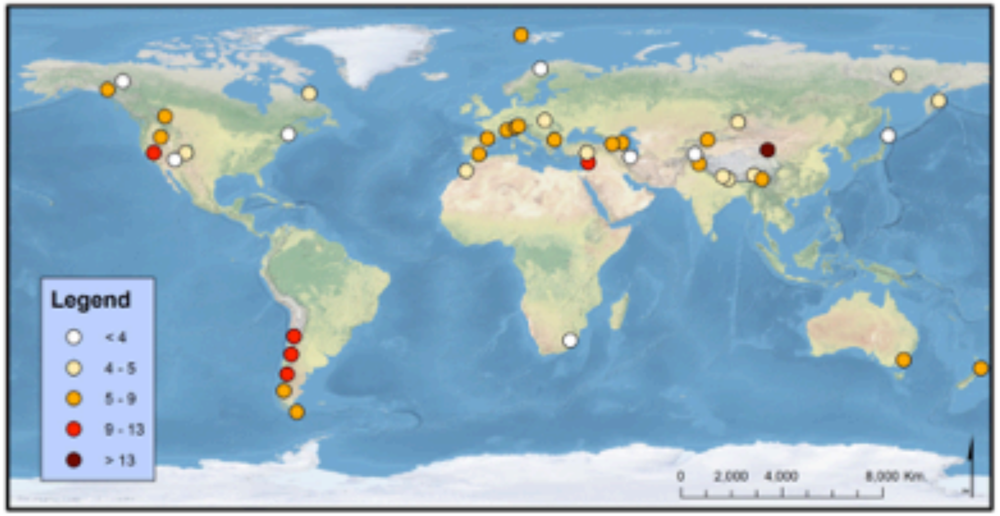
T0ºC



T+5ºC

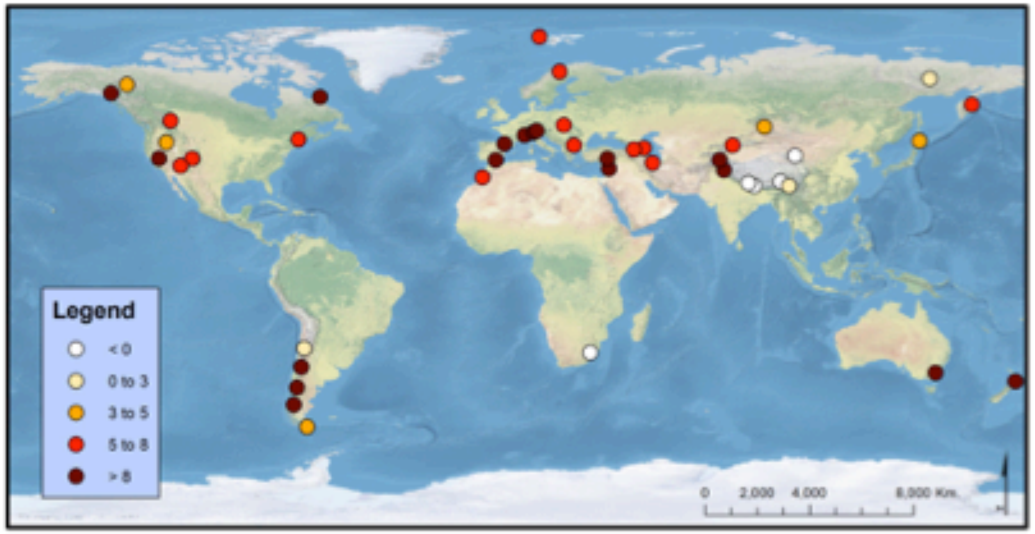


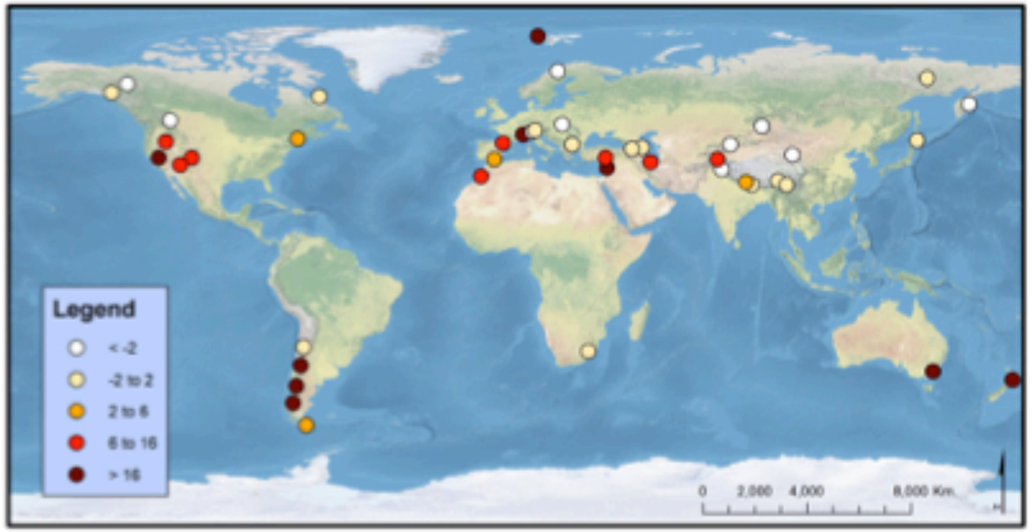
Hydrological sensitivity



Ratio Snowmelt/Qannual

D50

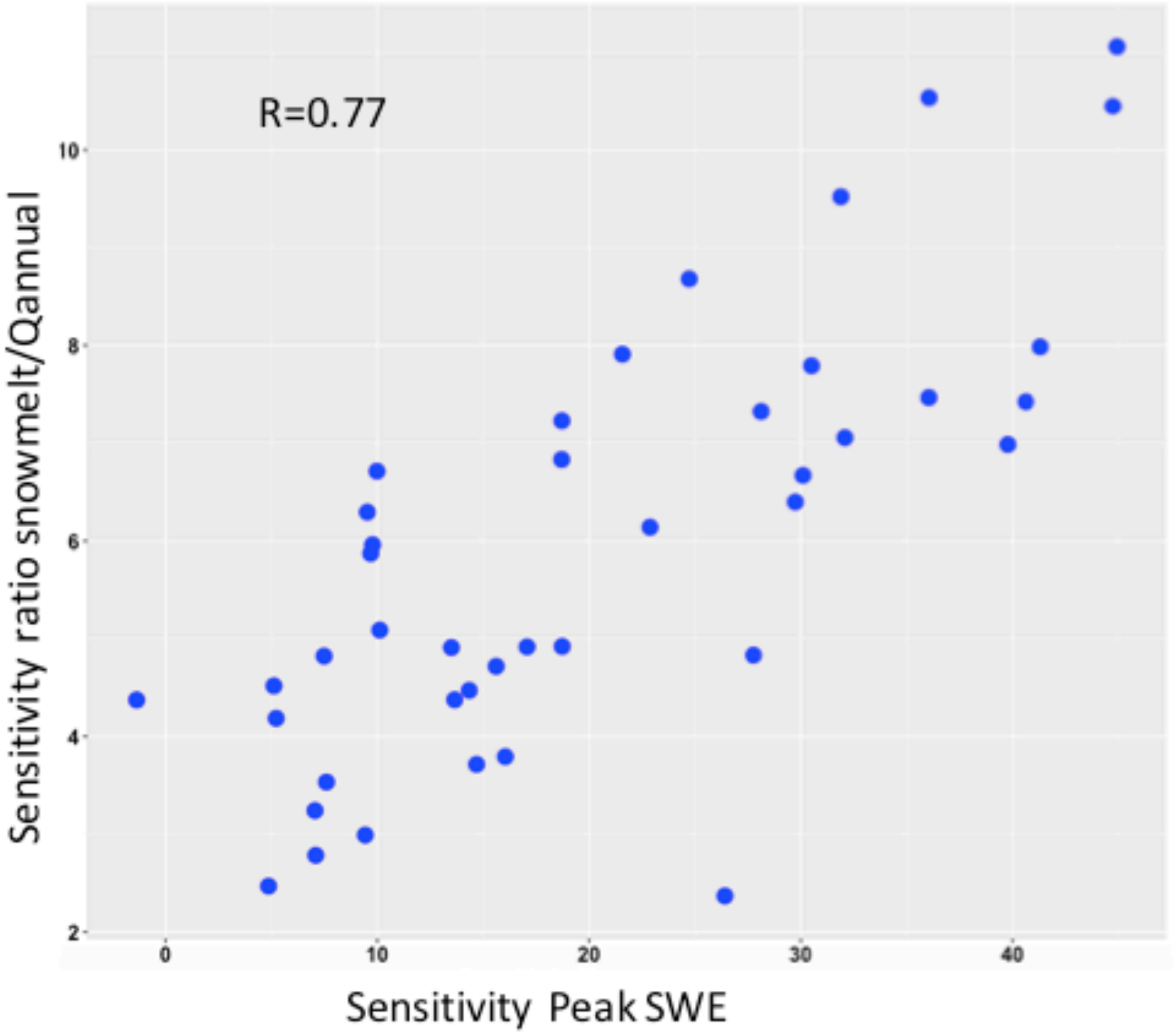


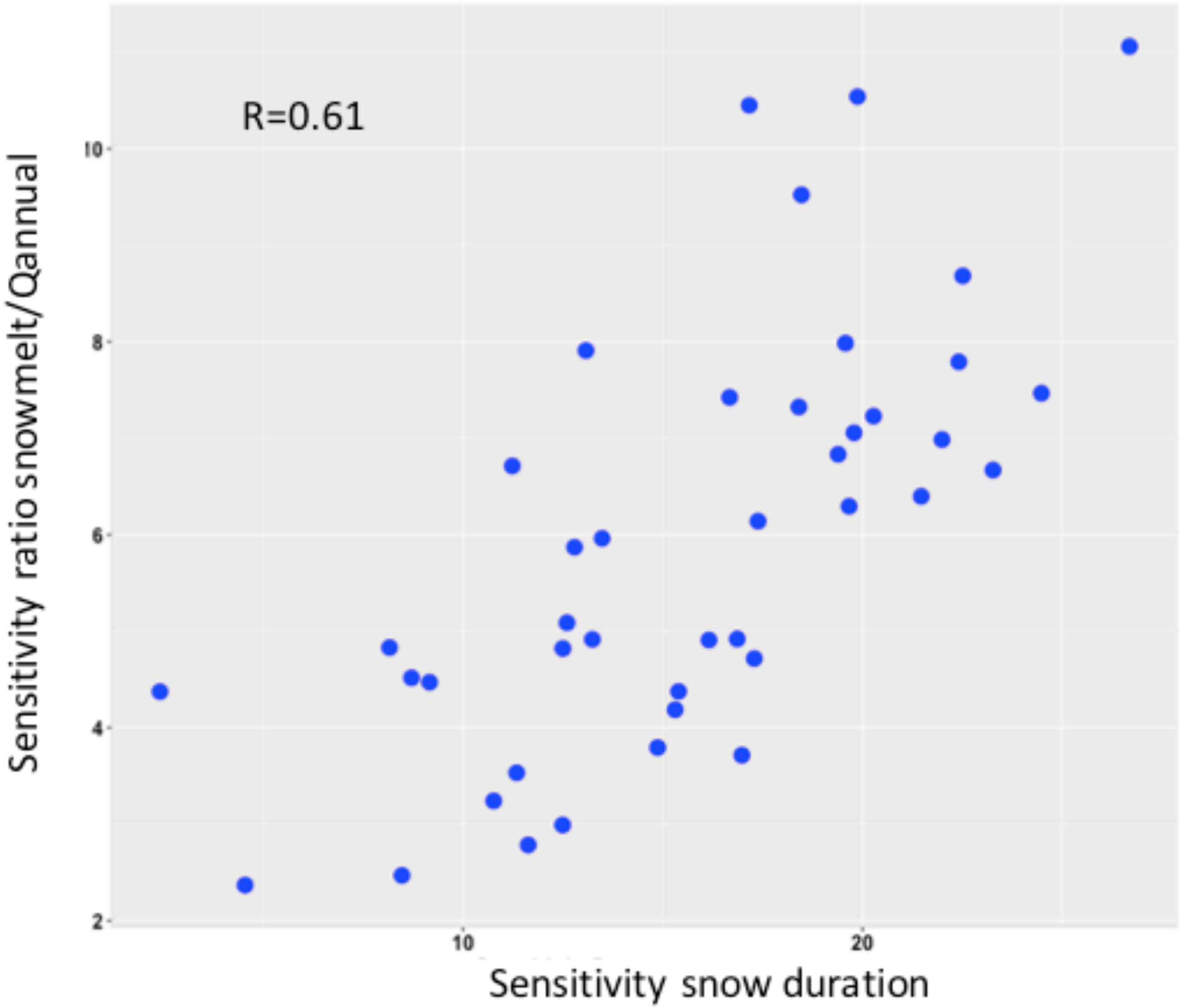


Snow damming

Hydrological sensitivity

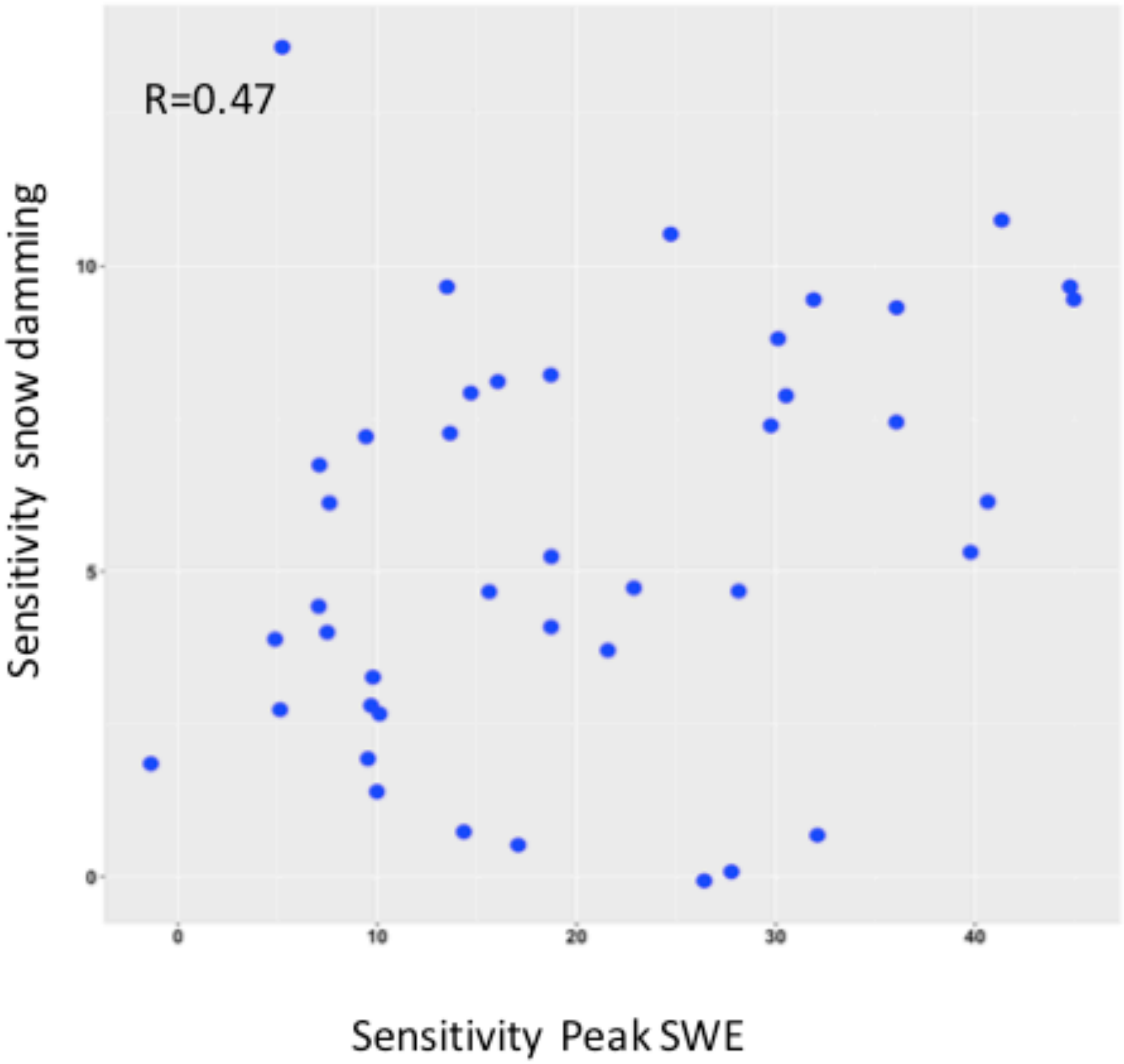
Sensitivity of snowmelt/Qannual *versus* sensitivity SWE peak and snow duration

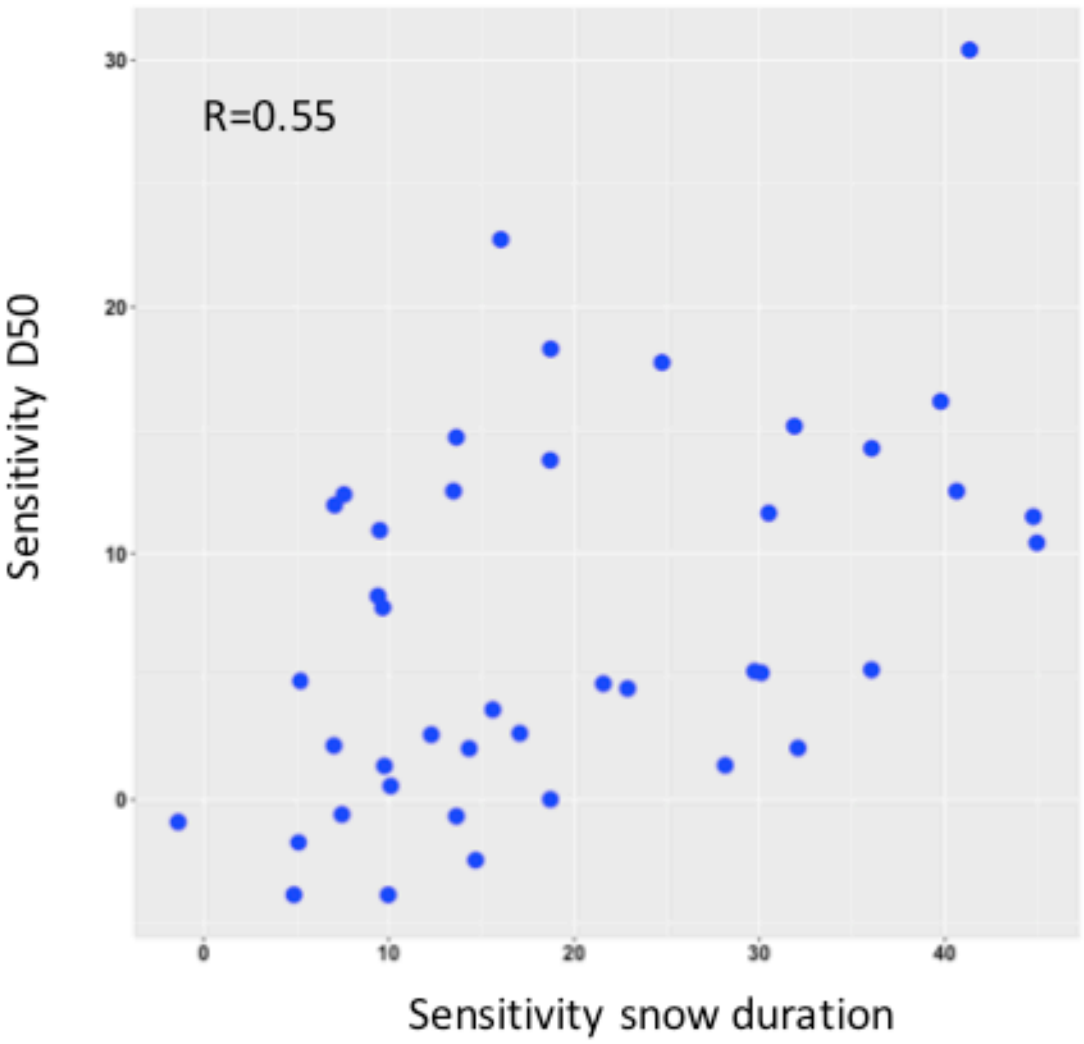




Hydrological sensitivity

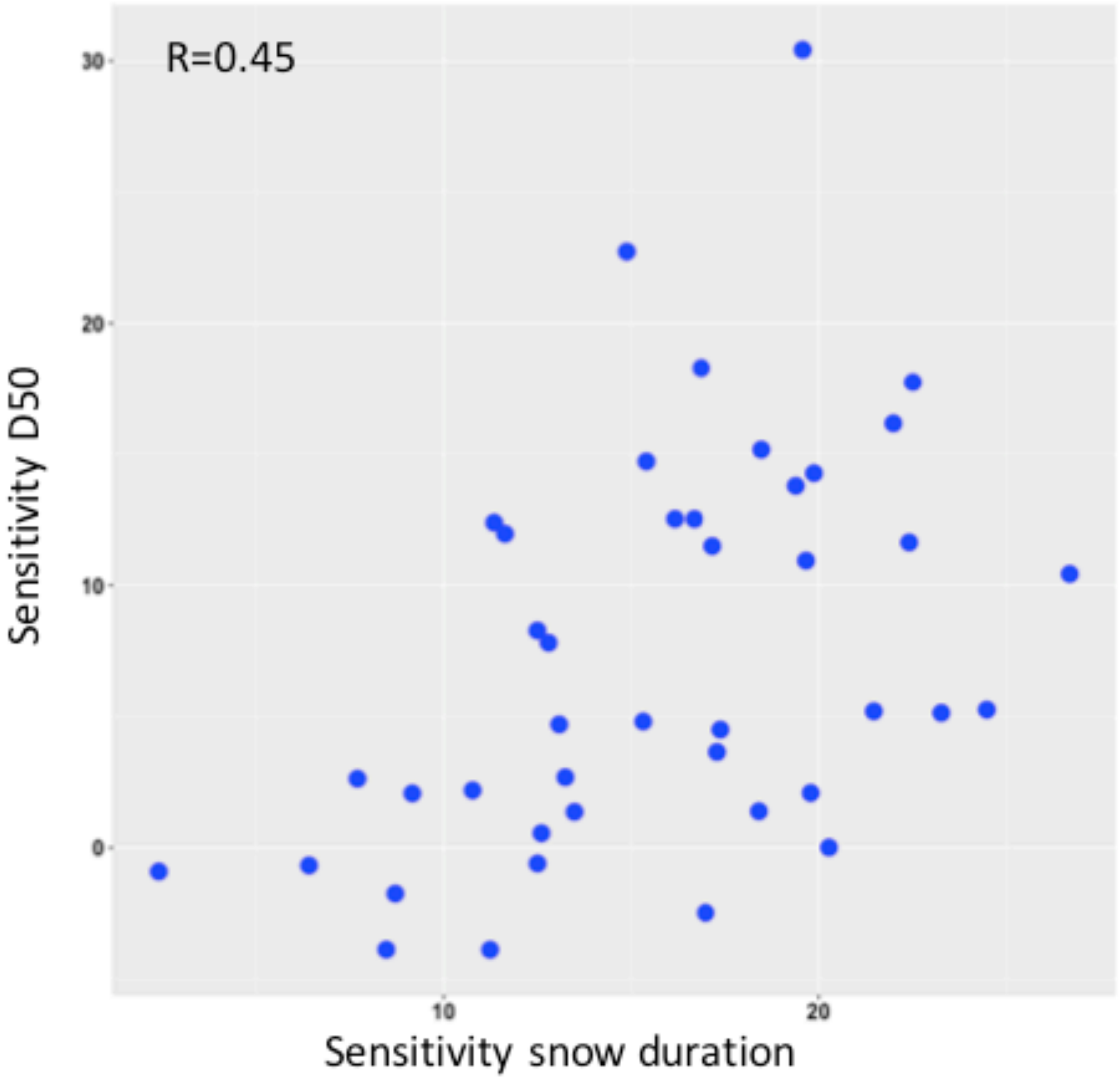
Sensitivity of Snow damming *versus* sensitivity SWE peak and snow duration

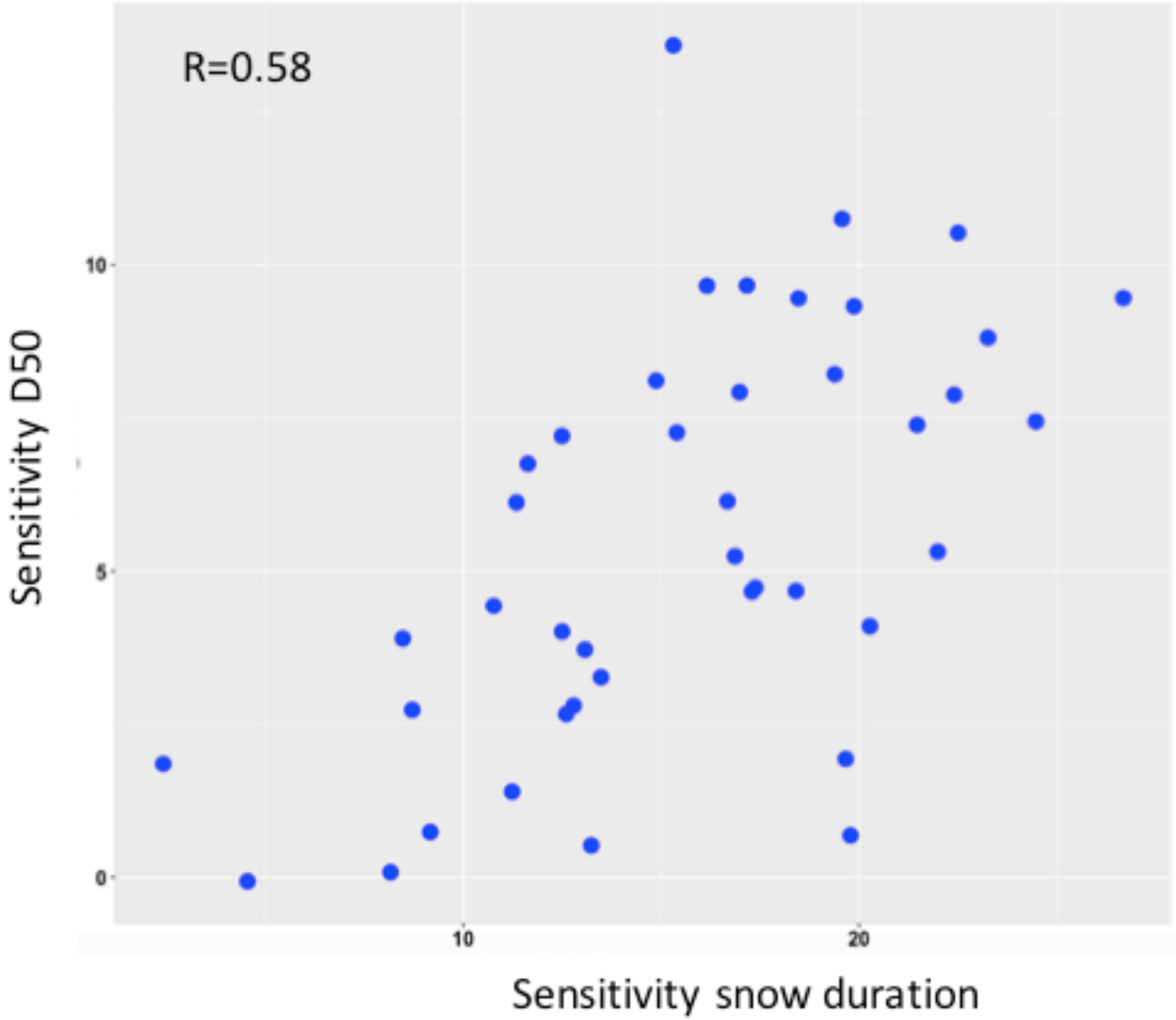




Hydrological sensitivity

Sensitivity of D50 (center of mass) *versus* sensitivity SWE peak and snow duration



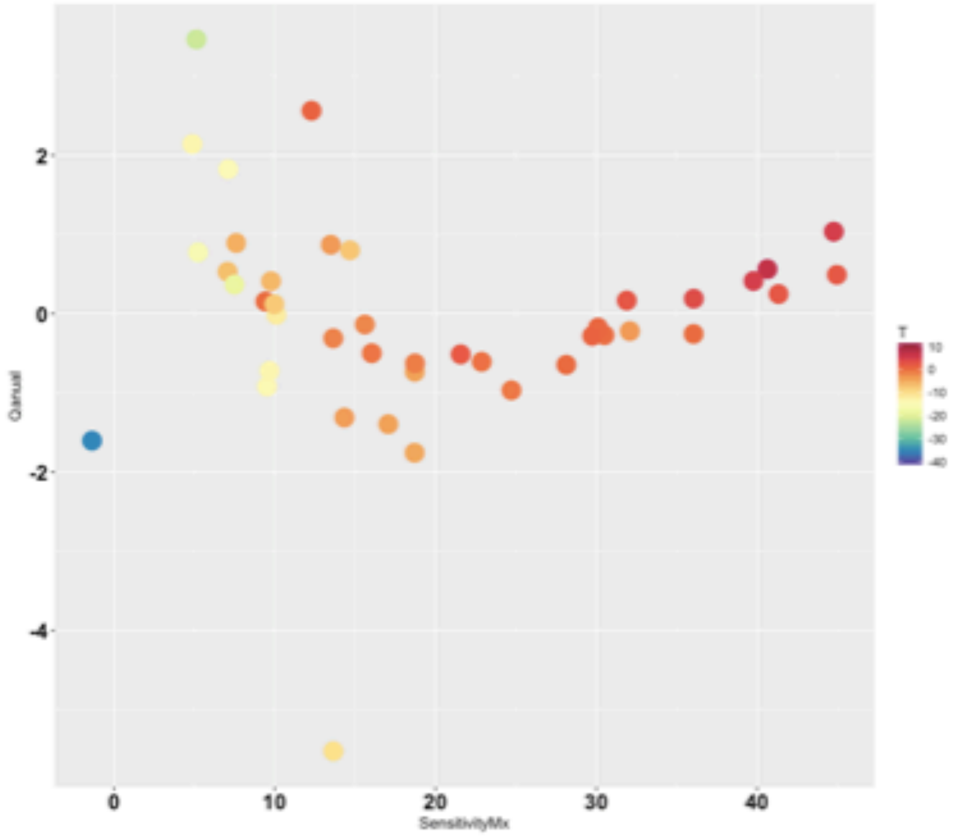


Hydrological sensitivity

Sensitivity of Qannual versus sensitivity SWE peak and snow duration

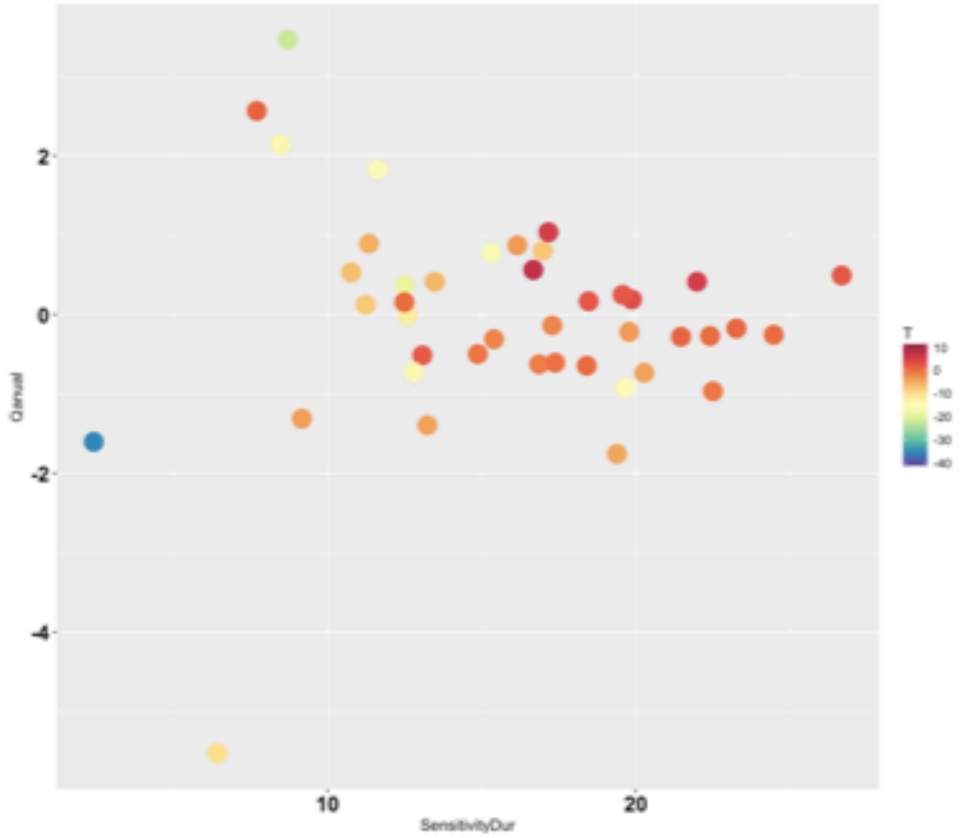
R=0.32

Sensitivity Qanual



Sensitivity Peak SWE

R=0.61



Sensitivity snow duration

Conclusions

SNOWPACK

- We found a very strong variability in snowpack sensitivity to increasing temperatures.
- Temperature of the basin (distance to 0ºC isotherm) controls closely the precipitation phase and the sensitivity of Peak SWE.
- With temperature and vapor pressure more than 80% of the variance of sensitivity of peak SWE is explained: **Good predictability.**
- Snow duration more difficult to be predicted from diagnosis variables.

HYDROLOGY

- As temperature will warm mountain´s runoff will be decoupled from snowpack regimes.
- The sensitivity of ratio of % of Qannual from snowmelt is closely linked Peak SWE runoff, so can be easily predicted.
- Indices related with the seasonal behaviour of river regimes (i.e. snow damming and D50) are less related with snowpack. sensitivity. Sensitivity of snow duration explains better the response of river regime changes to warming: Worse predictability.
- We have not found clear impact of warmer temperatures and less snow on annual runoff.

Conclusions

To keep in mind

– Sensitivity was calculated for T0ºC to T+5ºC, changing the range may introduce changes in the average sensitivity values.

– It is difficult to find good indices to define shifts in hydrological regimes because they are affeced by seasonal distribution of precipitation.

– Real basins compared to ideal basins would introduce much more complexity in the hydrological response to warming: need of especific simulations at each place.

– Annual runoff might be affected by declining snowpacks in basins with deeper soils or groundwater recharge.

– Temperature is not the only variable that changes with the time and it is not necessarily the most important.

– Hypsometry matters

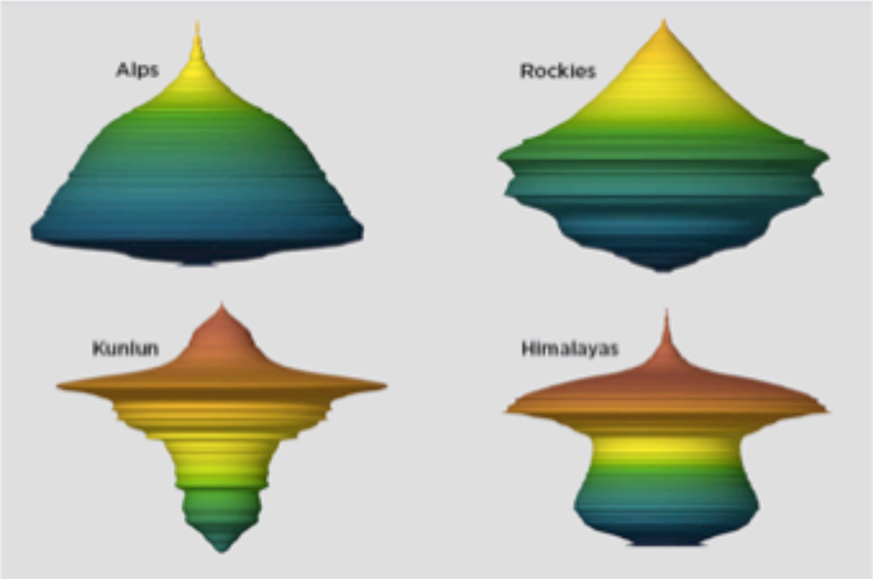
HYPSOMETRY MATTERS?

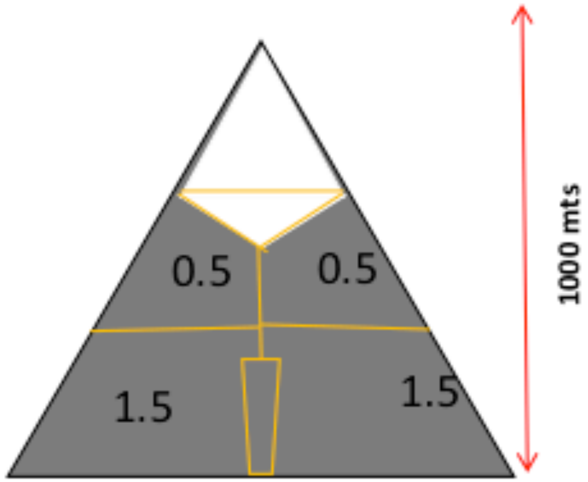
nature
climate change

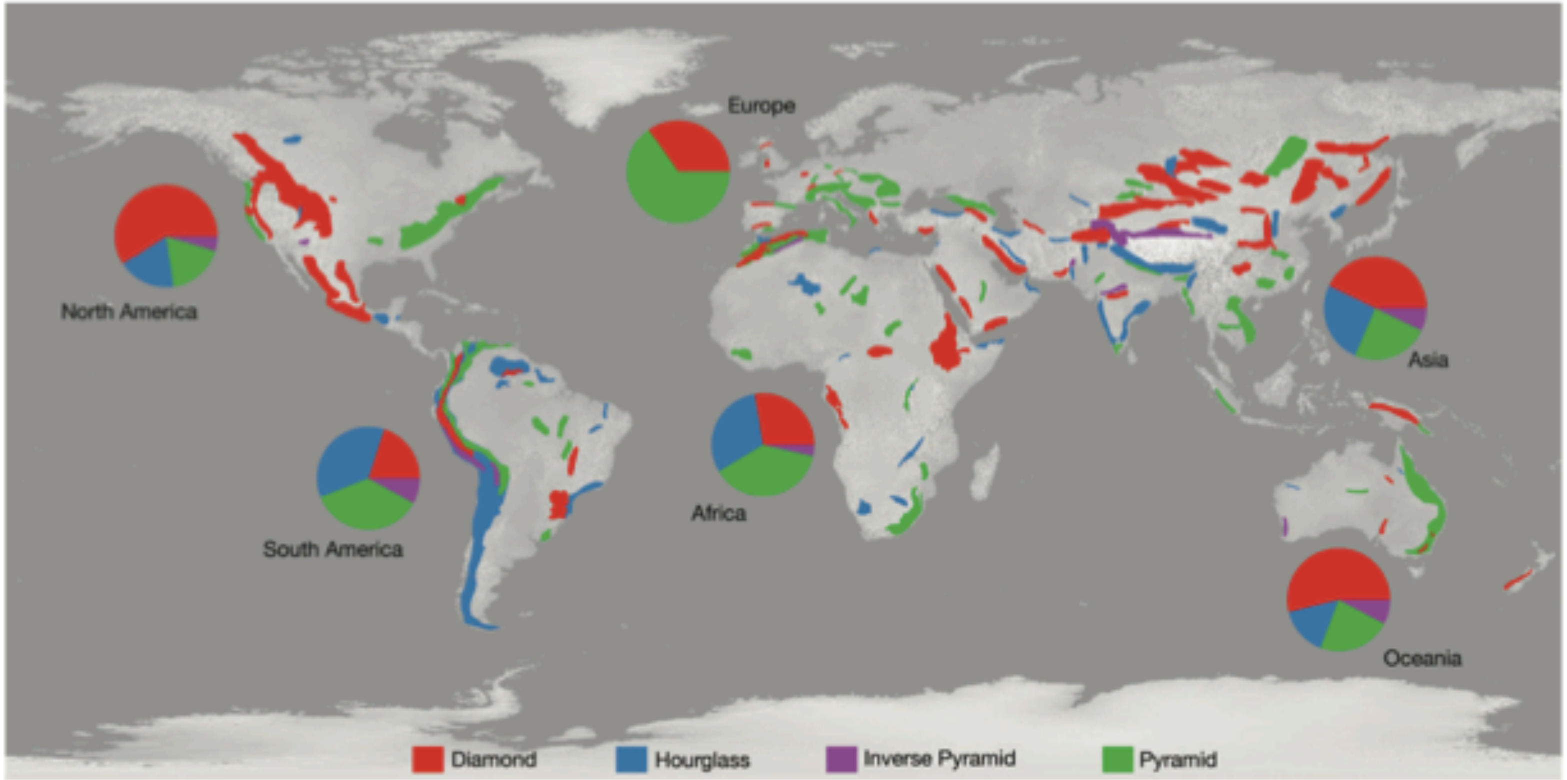
Letter | Published: 18 May 2015

Global mountain topography and the fate of montane species under climate change

Paul R. Elsen & Morgan W. Tingley



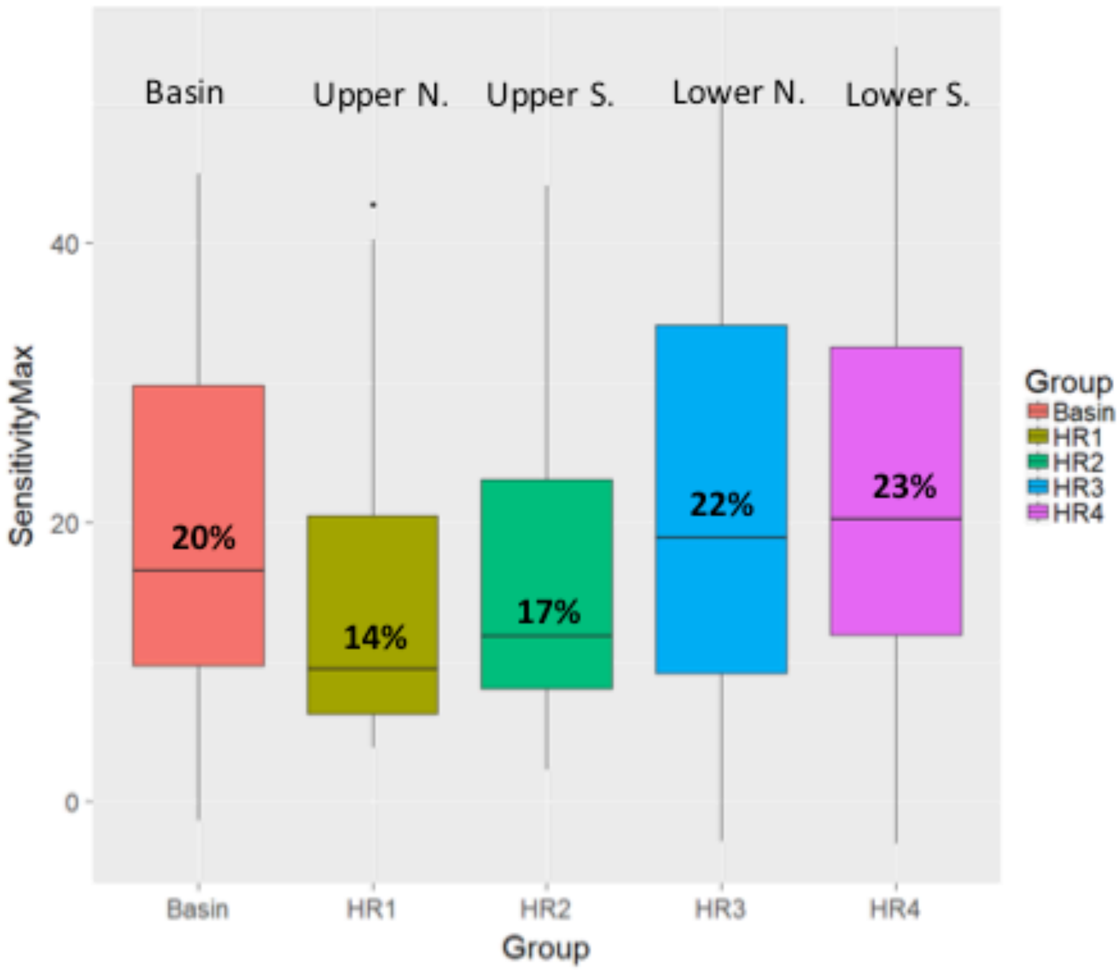





THANKS!!

Sensitivity of snowpack

Peak SWE



Snow duration