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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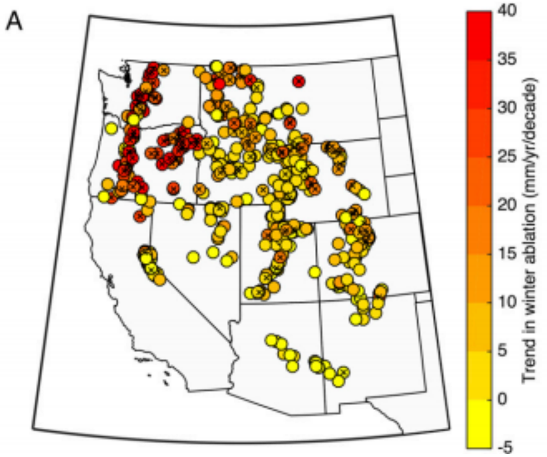
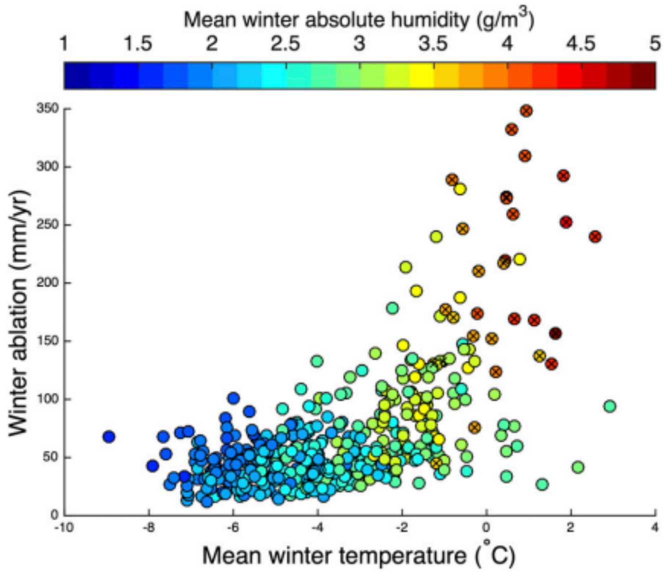
Edited by Andrea Rinaldo, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, and approved December 11, 2017 (received for review October 7, 2017)

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



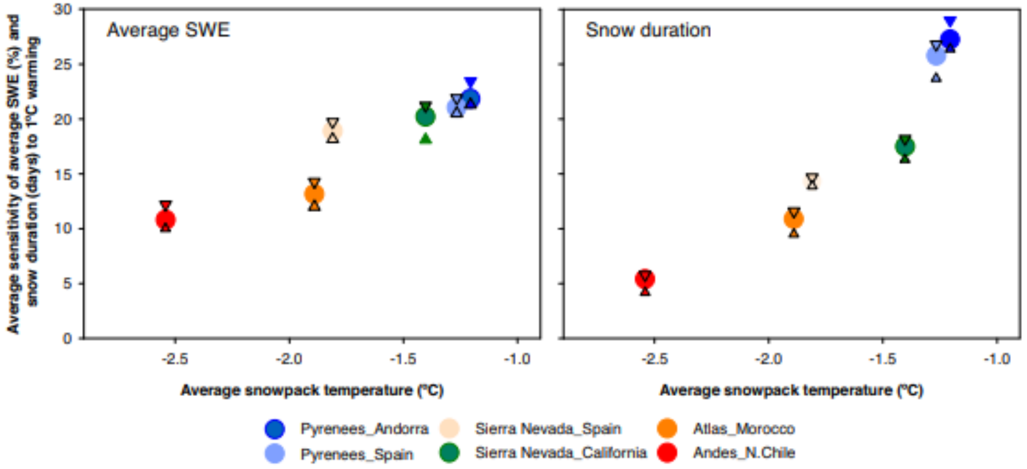


Environmental Research Letters

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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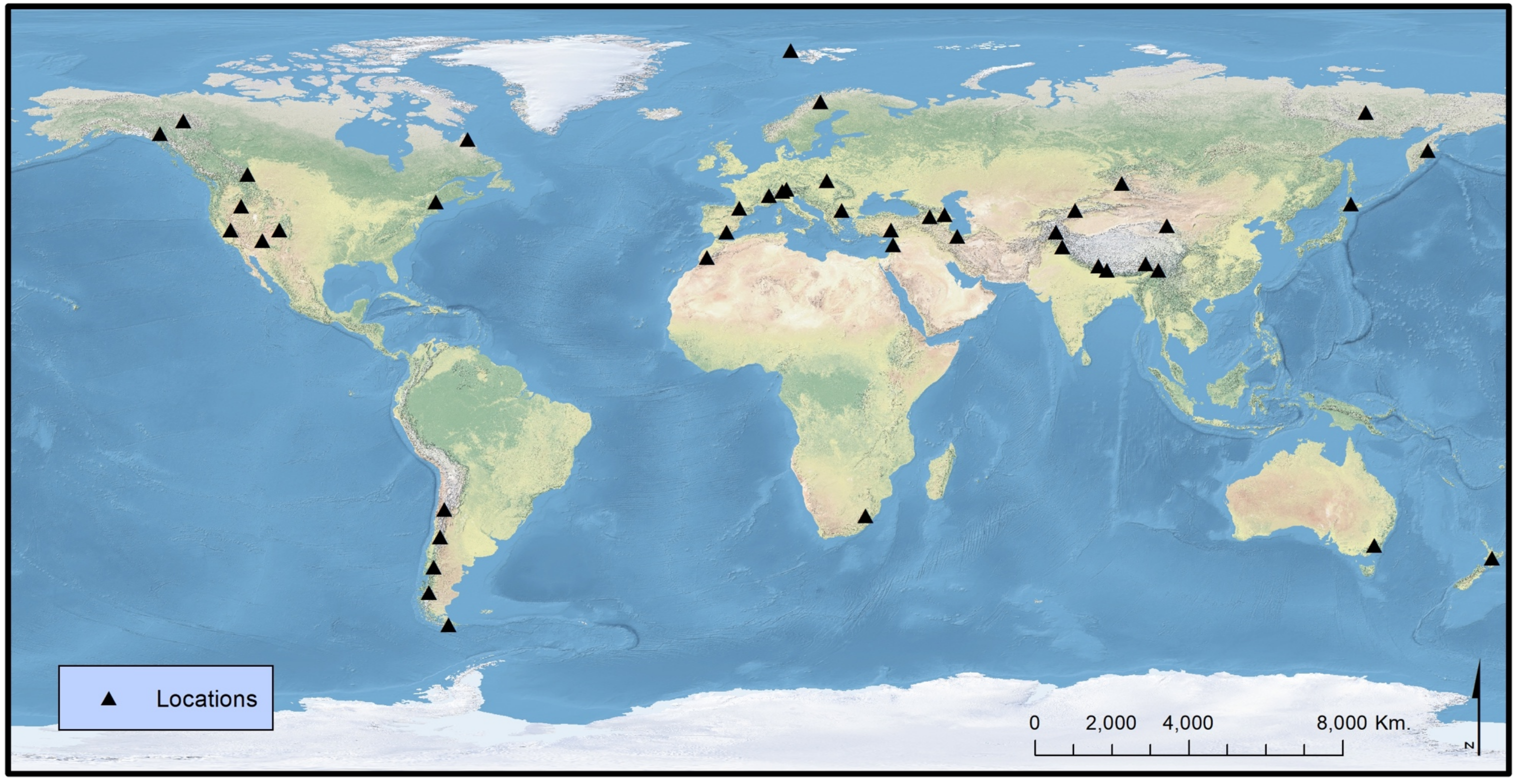
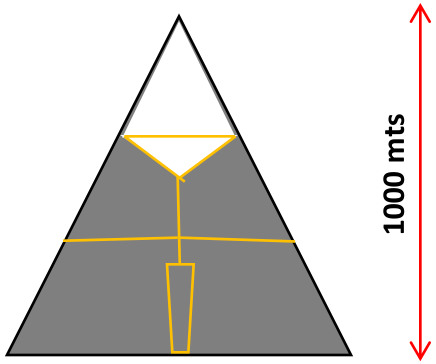
SOLUTION: VIRTUAL BASIN + REANALISIS DATA

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


WATCH
Water and Global Change

- Home
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- Global Modelling
- Publications
- Data for Researchers
- Info for Policy Makers
- Water Cycle Webpage
- Archive with News & Events
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SIXTH FRAMEWORK PROGRAMME

PRIORITY 6.3
Global Change and Ecosystems

Project Duration:
01.02.2007 - 31.07.2011

Data Availability

The WATCH project has produced a large number of data sets which should be of considerable use in regional and global studies of climate and water. Some of these datasets are described in the special collection, particularly Weedon et al. 2011 and Haddeland et al 2011. These data are all hosted by IIASA in Austria on a basic FTP site available to the public. For an introduction to the water cycle with illustrations of decadal averages plus visualisation of available data, see www.waterandclimatechange.eu.

Included in the data sets are the meteorological data used by global hydrological or land surface models and model outputs for the 20th and 21st Centuries. All the WATCH data is in NetCDF format (Network Common Data Format see http://www.eu-watch.org/watermip/data-format). NetCDF is an extremely efficient data format for large volumes of data and is becoming popular with modellers as both an input and output format. Data conforms to the ALMA-data exchange convention; for more information, please see http://www.lmd.jussieu.fr/~polcher/ALMA/. We have introduced a web based system to catalogue these data which can be accessed via the CEH Gateway catalogue (https://gateway.ceh.ac.uk/). Use the search term WATCH in the gateway site to find a list of the available data.

The data has been developed and/or produced for the purposes of the WATCH project and no warranty is given as to its suitability for use by the user. No liability is accepted by the WATCH project and its members for any errors or omissions in the data or associated information and/or documentation. Use of the data should include acknowledgement of the WATCH project, authors of the data and previously published texts. The appropriate references are included in CEH Gateway catalogue records. Users of the data should consult the citations and instructions as indicated in the "README files" stored with the Data on the IIASA ftp site.

Outline of what is available

1. **WATCH Forcing Data 20th Century**: a meteorological forcing dataset (based on ERA-40) for land surface and hydrological models (1901-2001). Five variables are at 6 hourly resolution and five variables are at 3 hourly resolution. View more
2. **WATCH-Forcing-Data-ERA-Interim**: WFDEI was produced post-WATCH using WFD methodology applied to ERA-Interim data. It is a meteorological forcing dataset extending into early 21st C (1979 – 2012). Eight meteorological variables at 3-hourly time steps, and as daily averages. See Read me (pdf) for explanation and access codes
3. **WATCH Driving Data 21st Century**: similar to the WATCH forcing data but for the 21st Century and is constructed from model output not interpolated observational data. Two climate scenarios, B1, A2 and a Control were each run through three global climate models (CNRM, ECHAM5 and IPSL) to produce a total of 9 sets of future driving data at 0.5 degree resolution. View more
4. **WATCH 20th Century Model Output Datasets**: the WATCH forcing data has been run through nine land surface or global hydrological models, to produce a range of output variables. View more
5. **WATCH 21st Century Model Output**: the 21st century WATCH driving data was put through ten land surface and global hydrological models. View more
6. **20th Century Ensemble Data**: ensemble of model output data from 5 models for 4 hydrological variables, stored as daily data in monthly netCDF files
7. **Test Basin data**: 21st C driving data for each test basin (Crete, Glomma, Nitra, Upper-Elbe, Upper Guadiana)

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

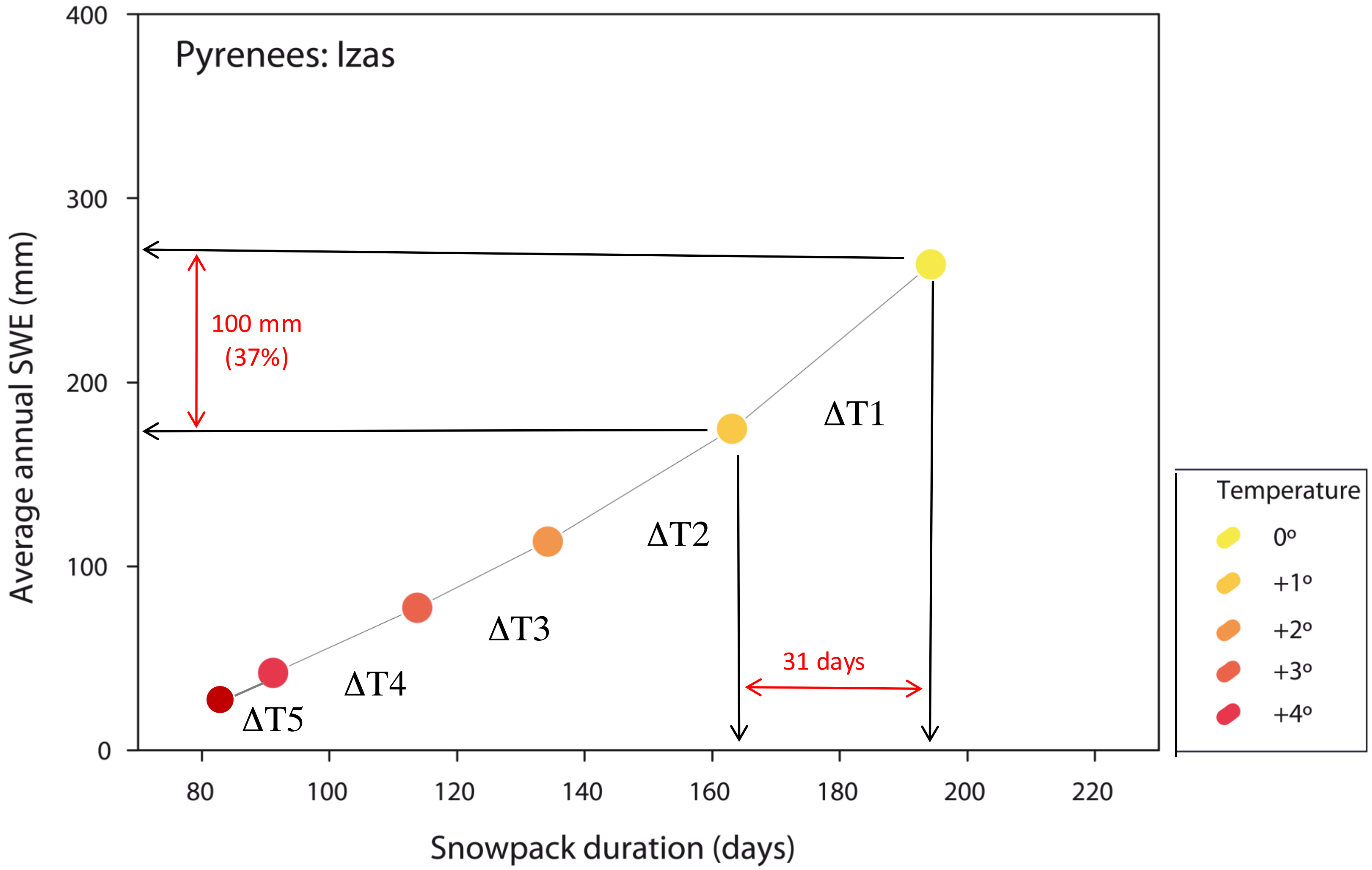
The aim is not having data that reproduces exactly the conditions of each point, but to ensure we are using coherent inputs gathering much of the climates found in snow dominated basins in the world

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



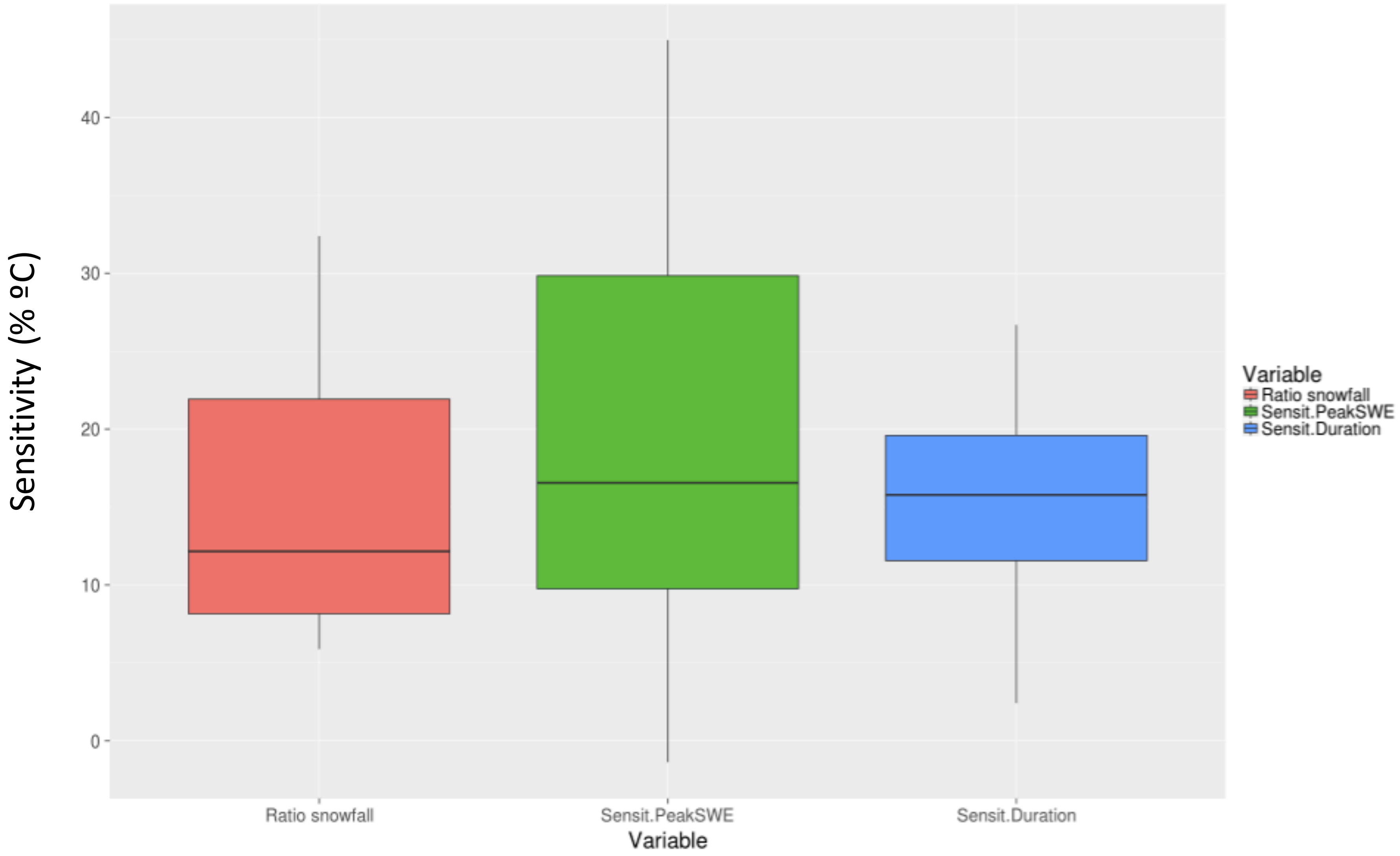
Questions

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

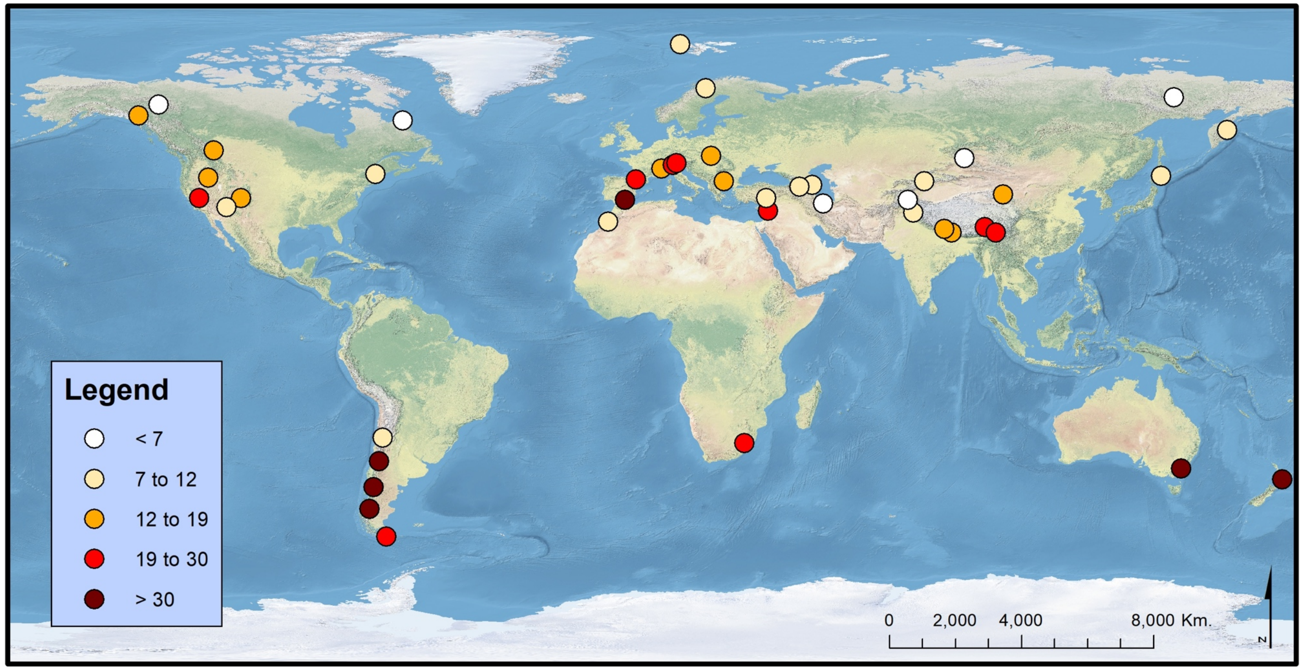
2- How do process interactions mediate sensitivity for snow regimes and for hydrology?

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

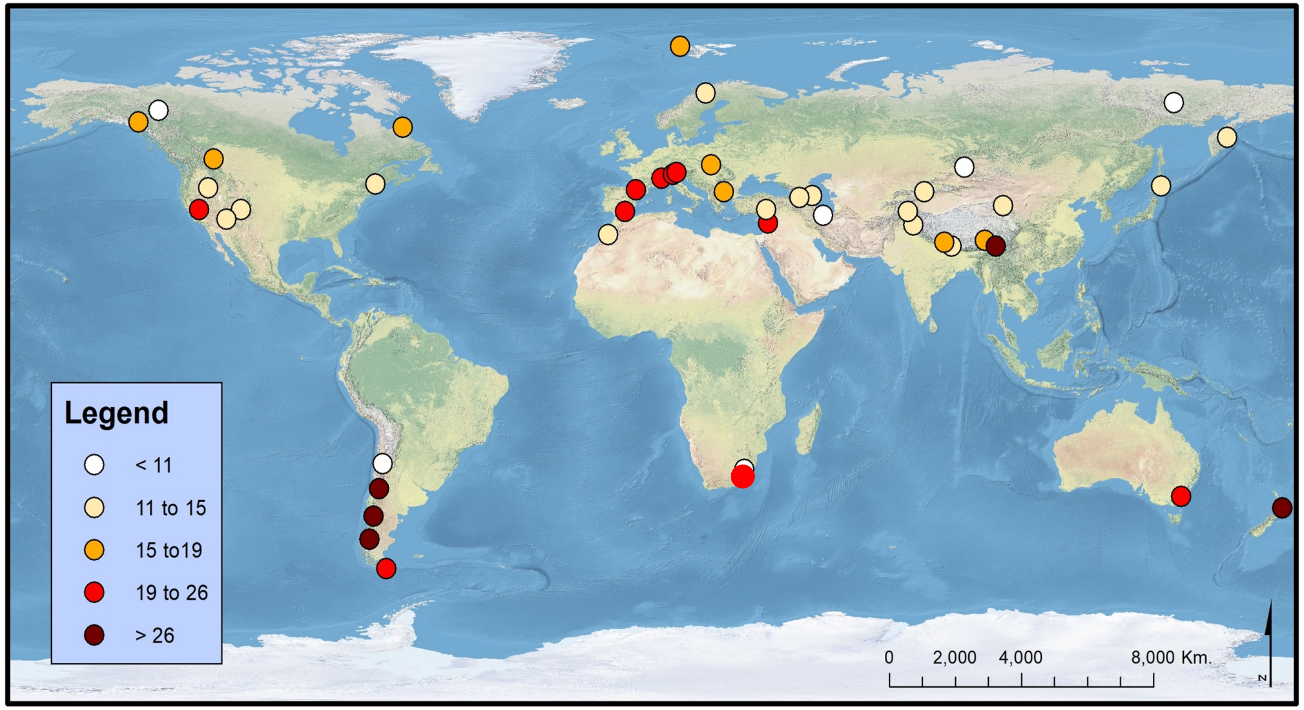
Sensitivity of snowpack



Sensitivity of snowpack

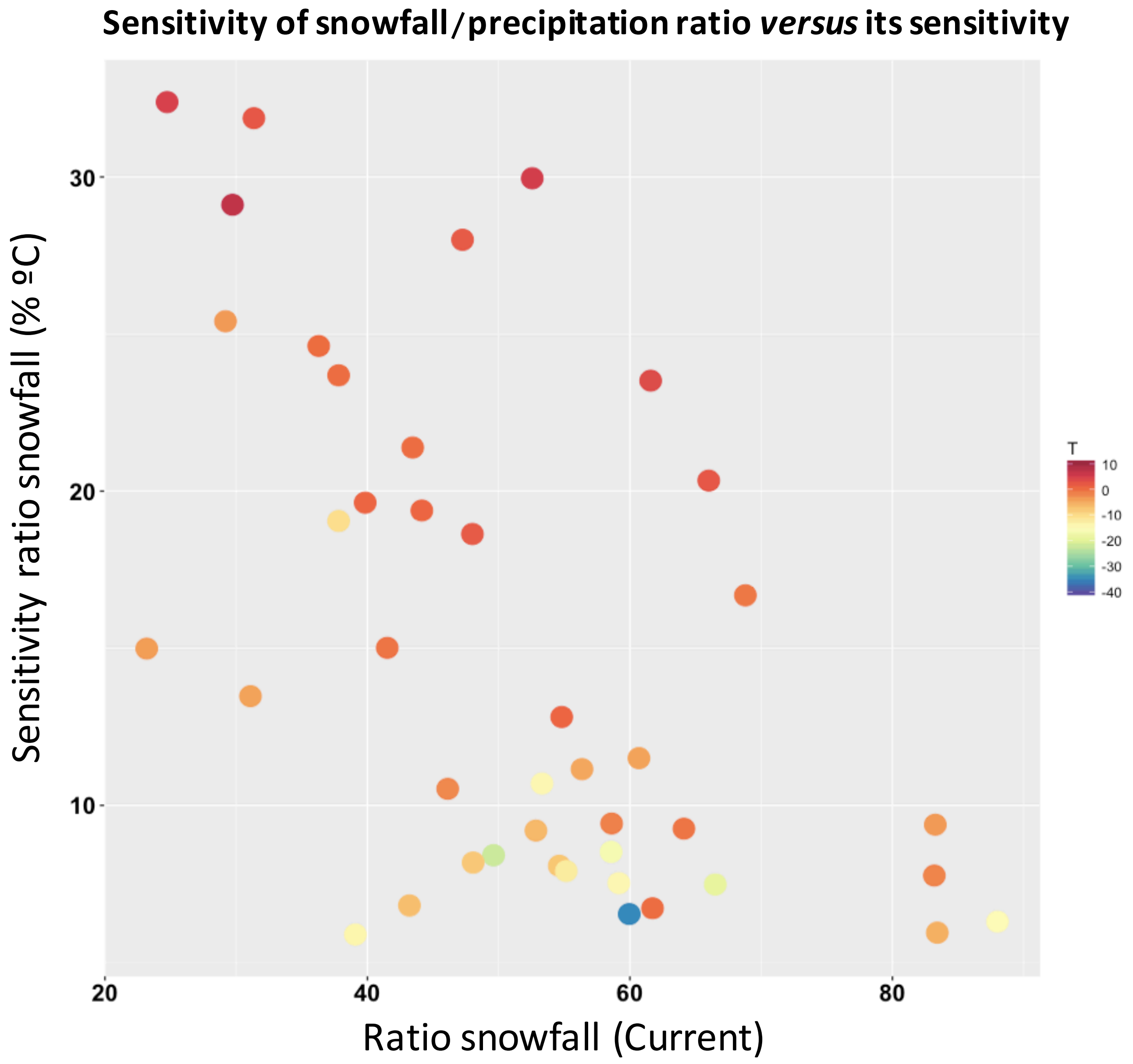


Sensitivity of Peak SWE

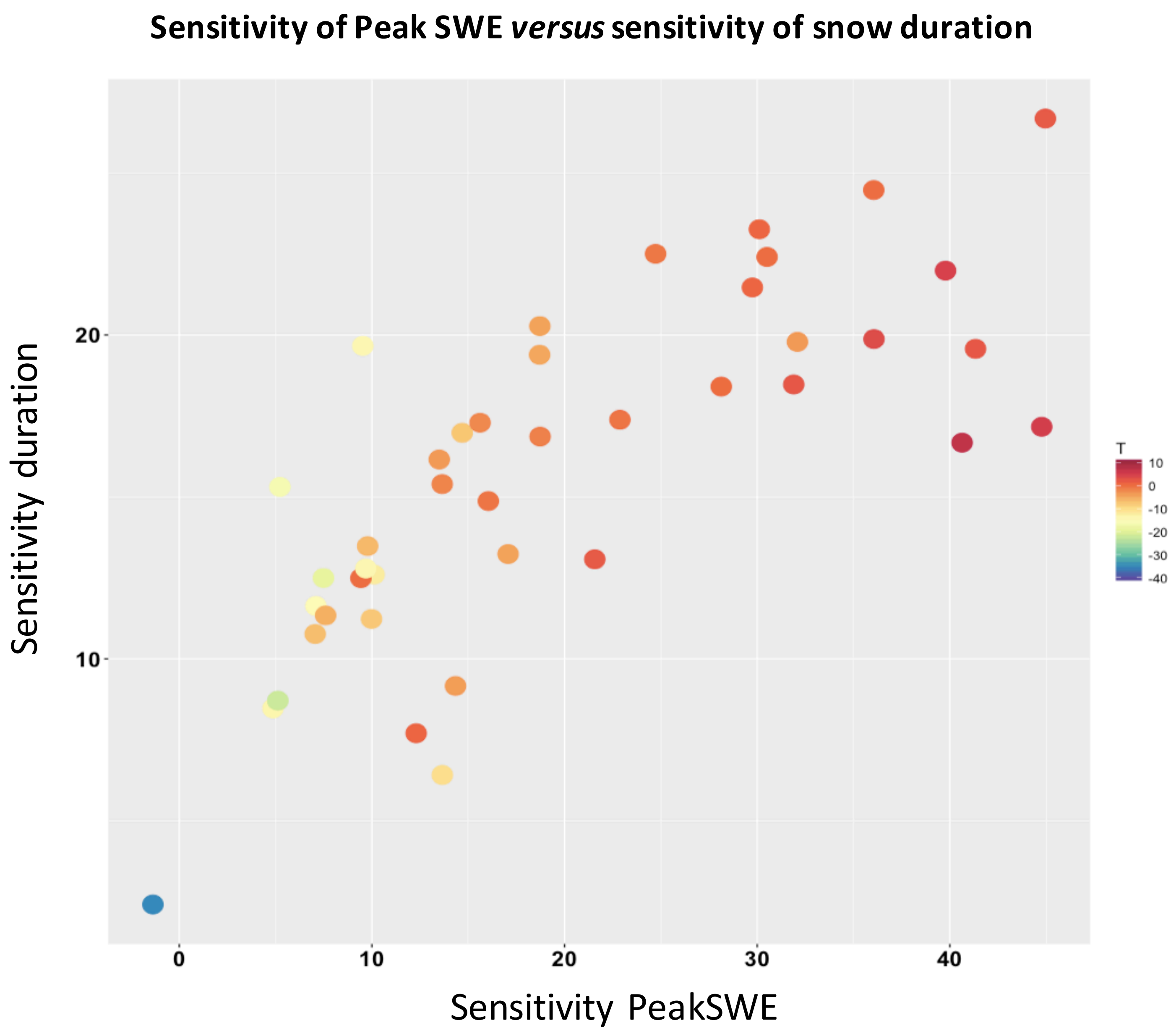


Sensitivity of snow duration

Sensitivity of snowpack

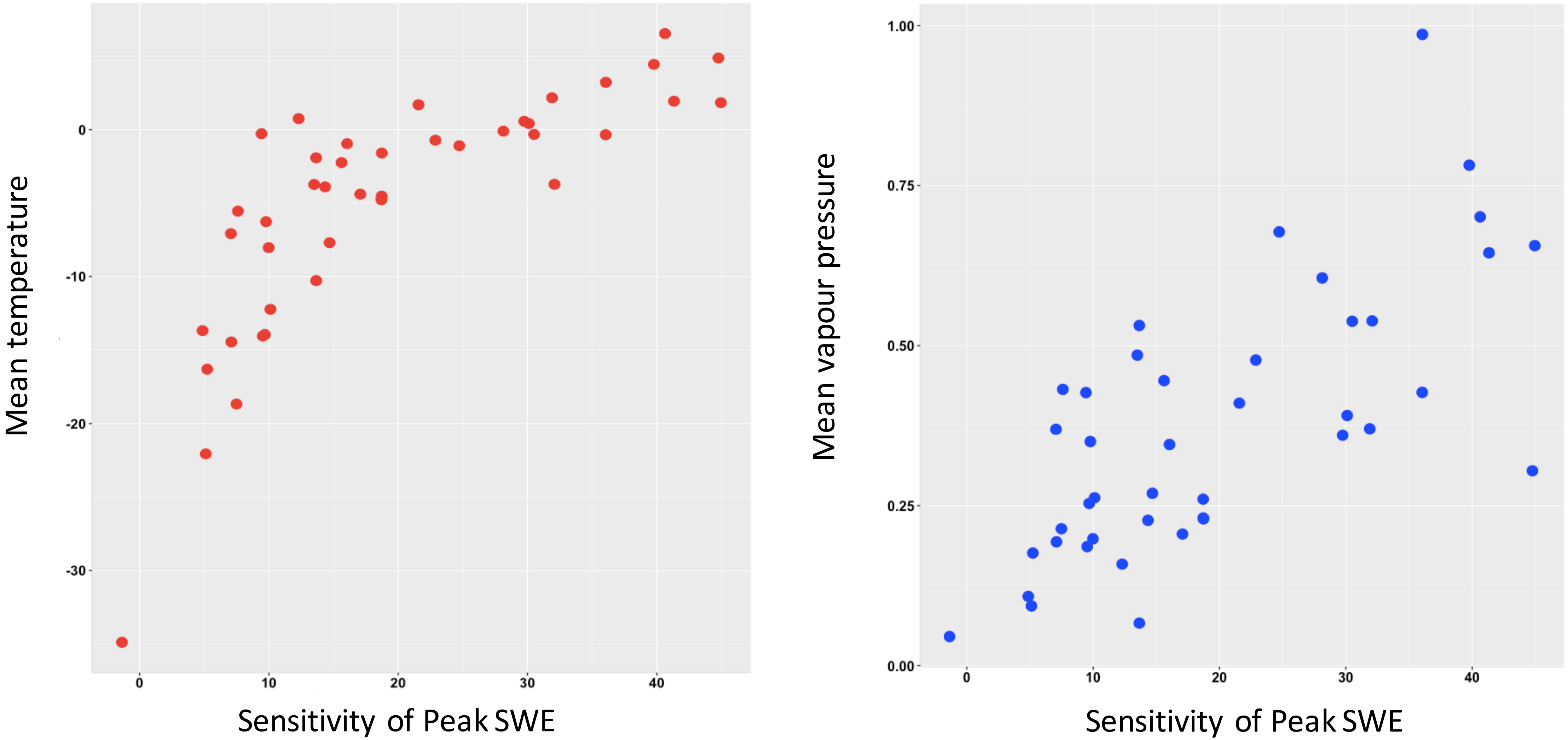


Sensitivity of snowpack



Sensitivity of snowpack

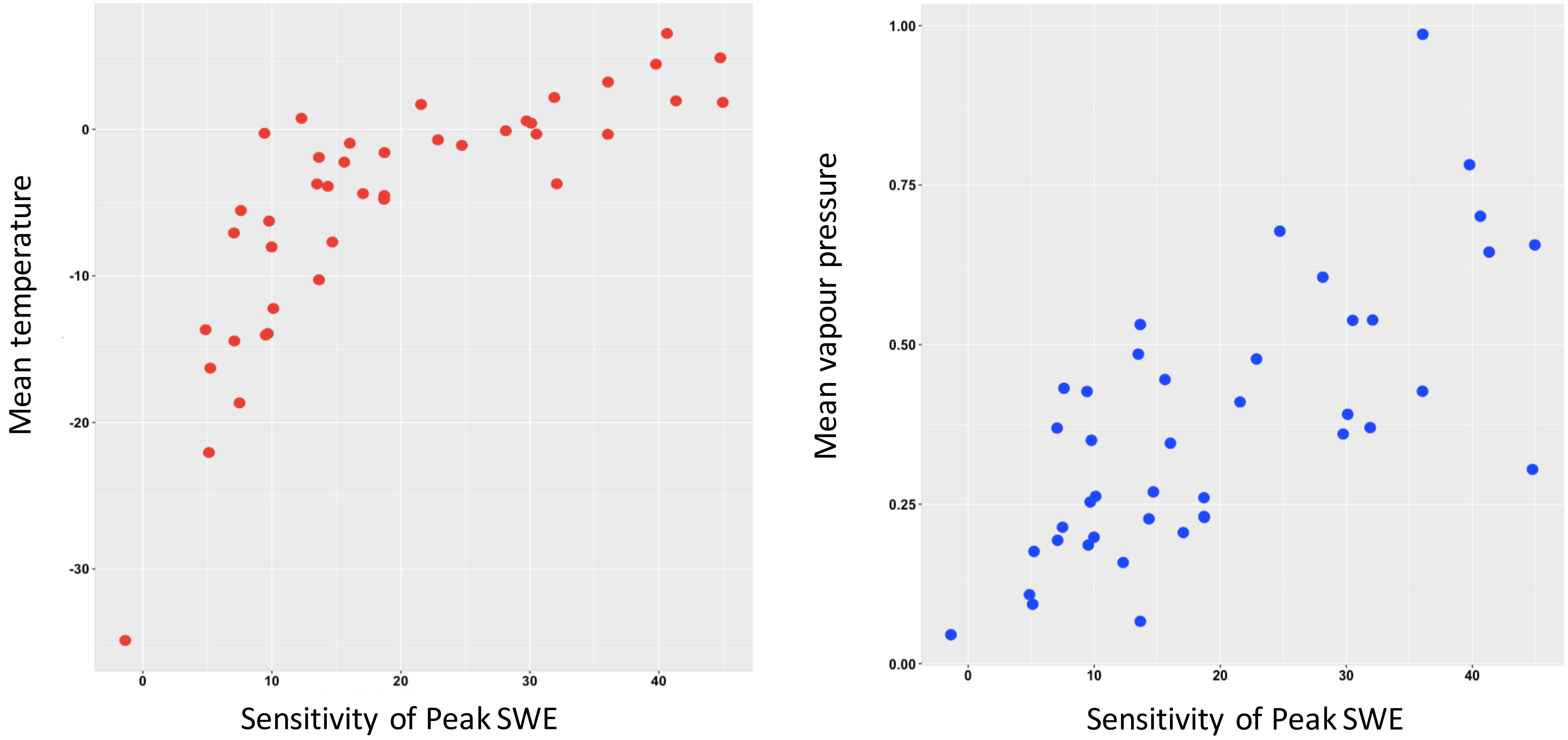
Sensitivity of Peak SWE *versus* temperature and vapour pressure



Sensitivity of snowpack

Linear regression model **r^2= 0.81**

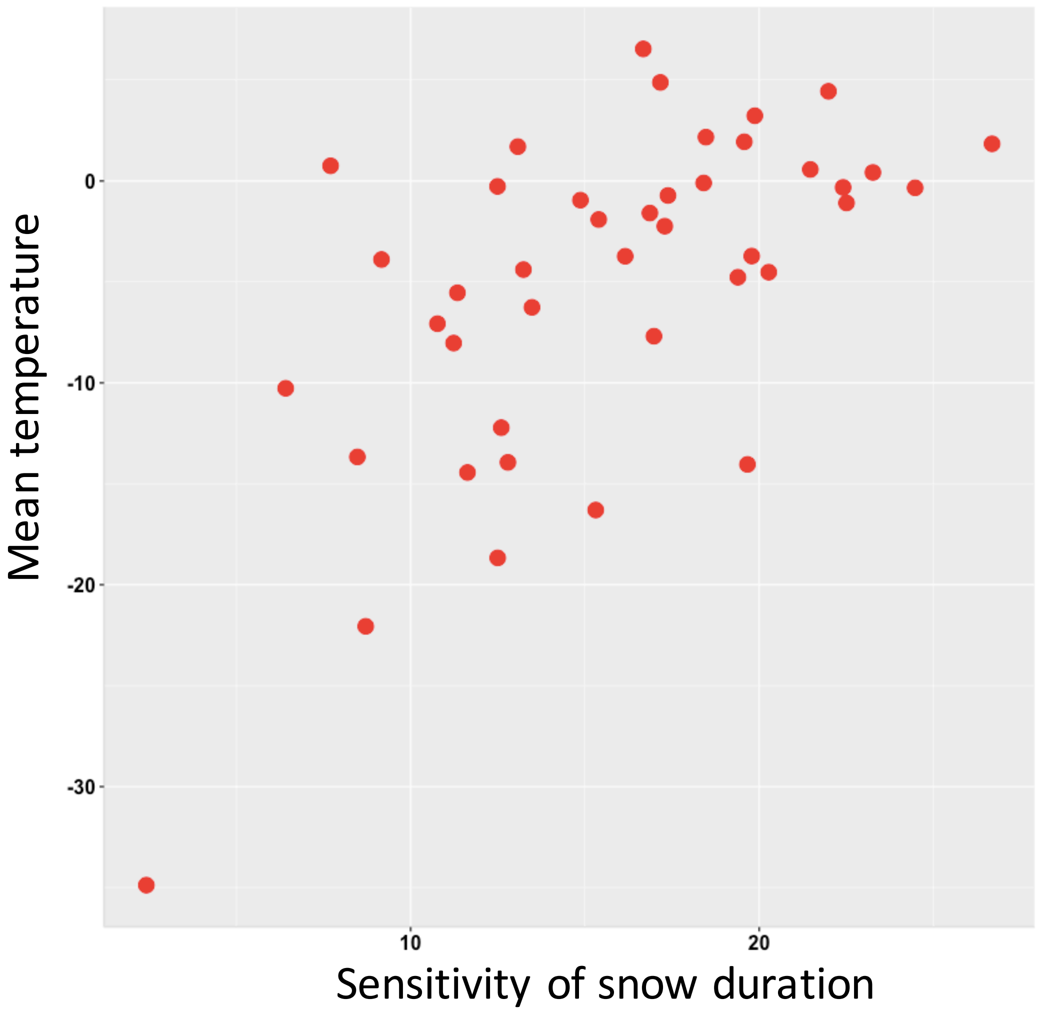
Sensitivity of Peak SWE *versus* temperature and vapour pressure

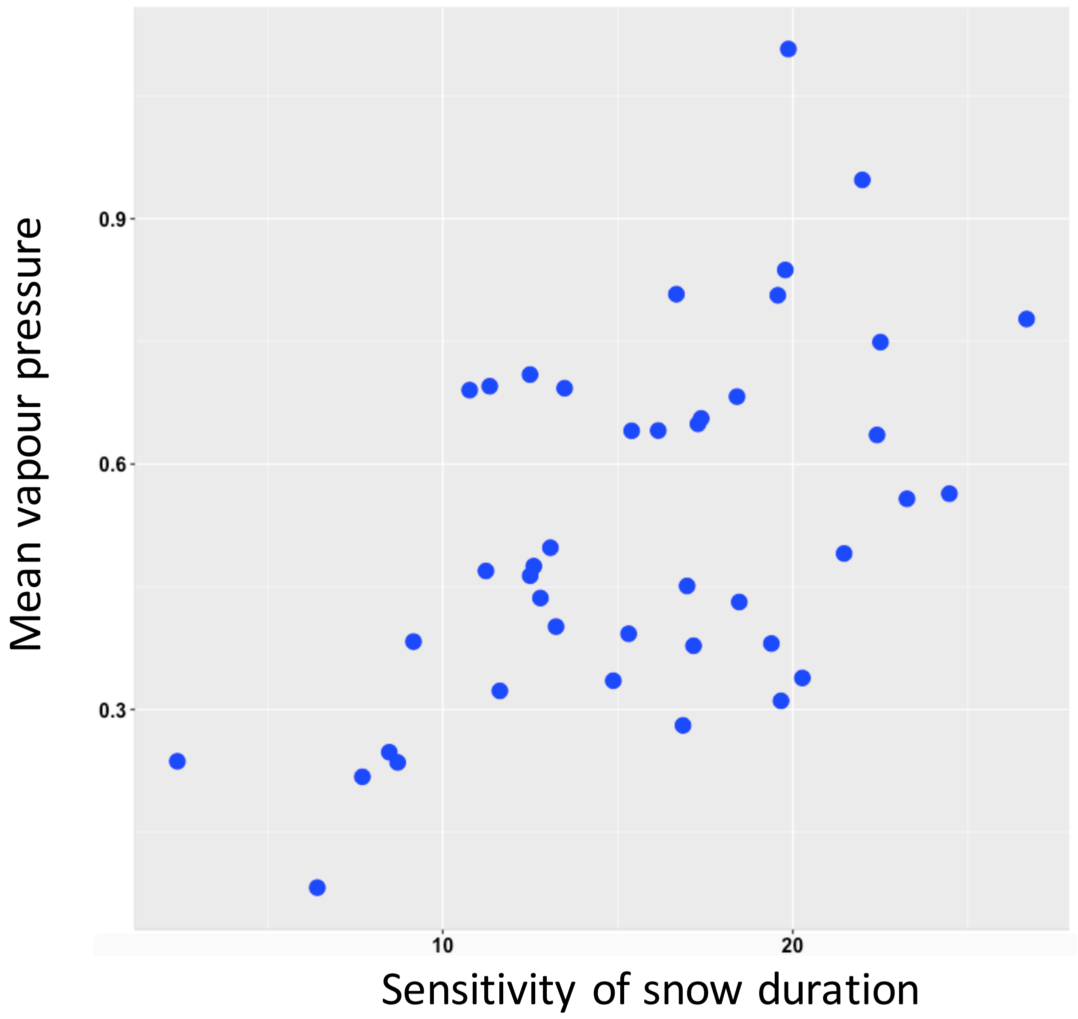


Sensitivity of snowpack

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

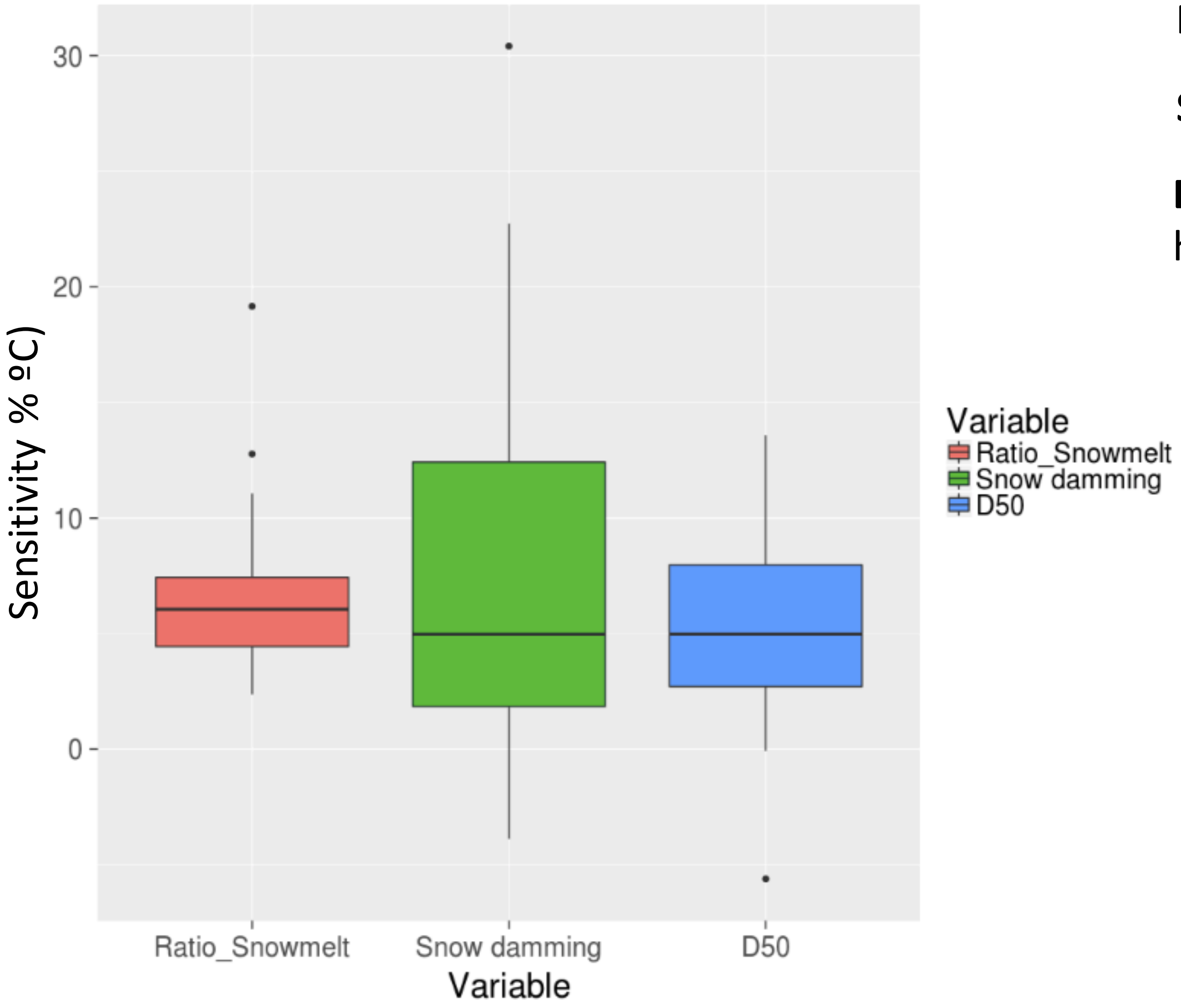
Sensitivity of snow duration *versus* temperature and vapour pressure





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

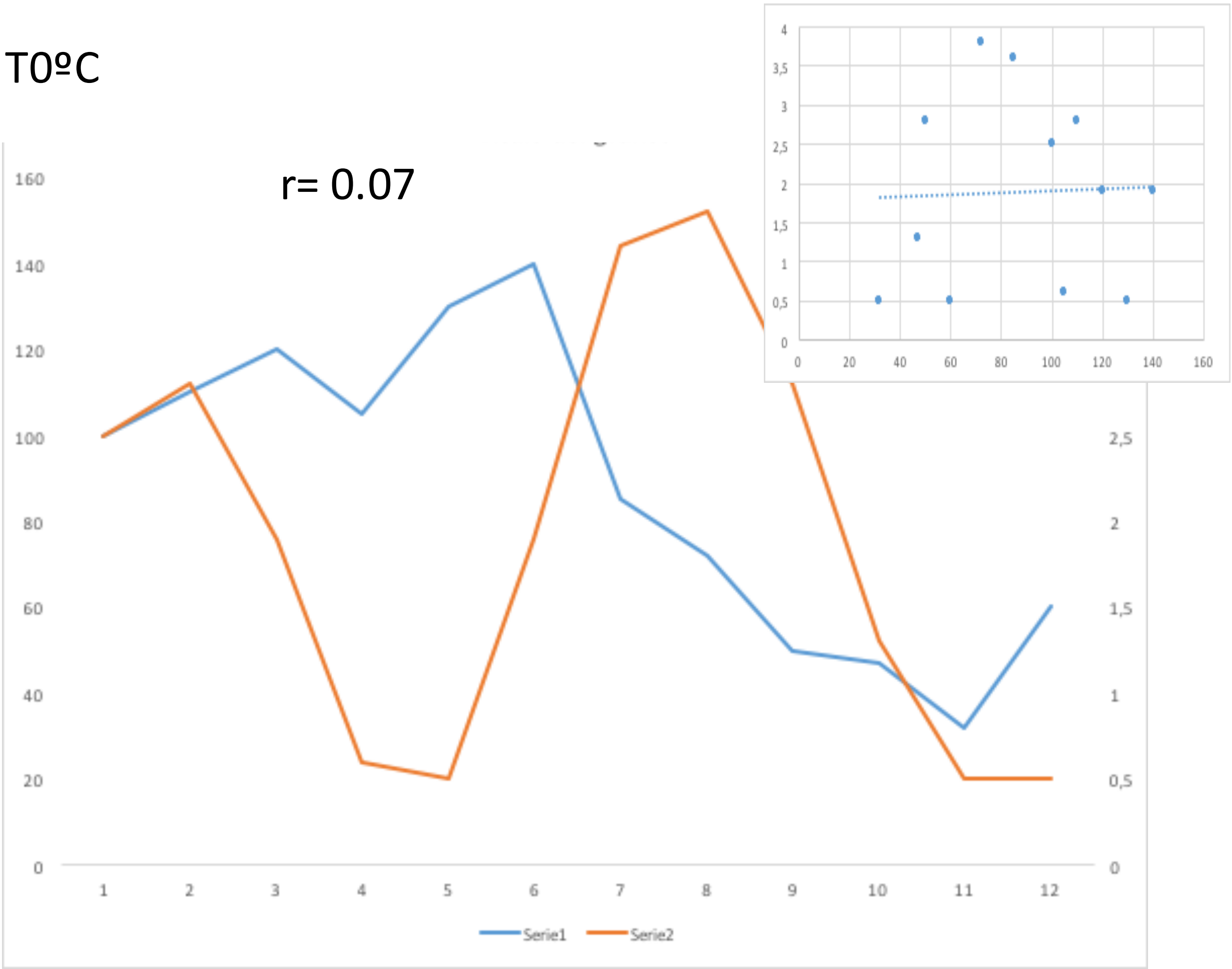
D50: Change in the day where the center of mass of the hydrograph occurs

Hydrological sensitivity

Snow damming

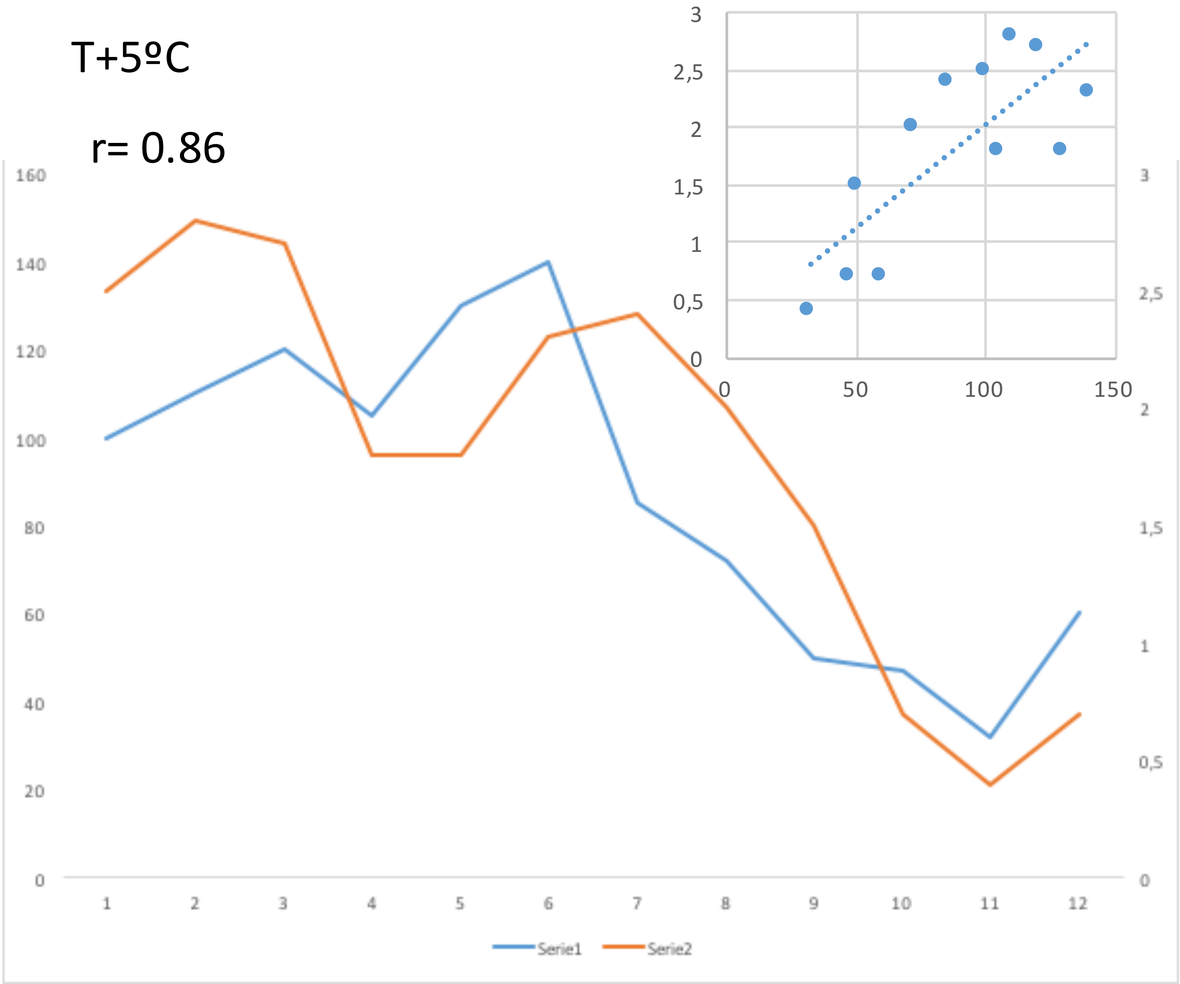
T0ºC

r= 0.07

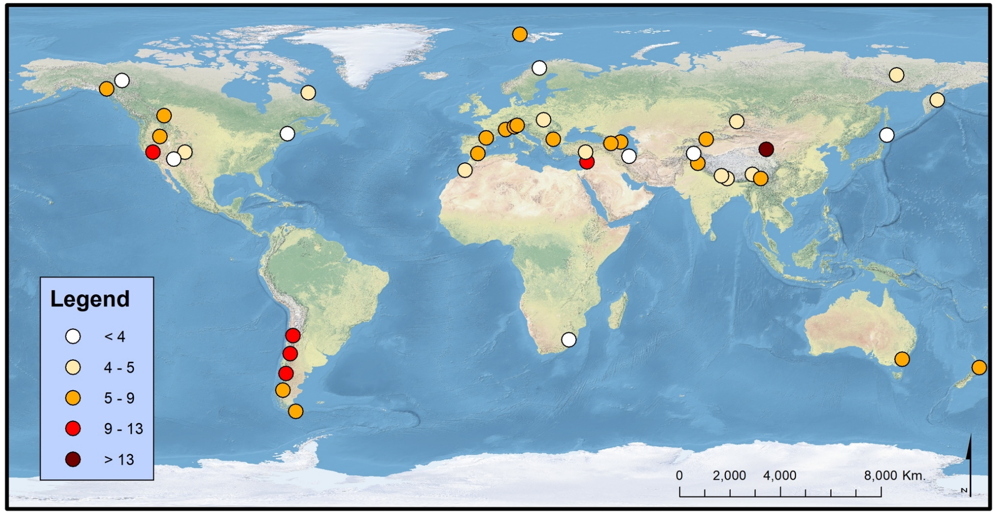


T+5ºC

r= 0.86

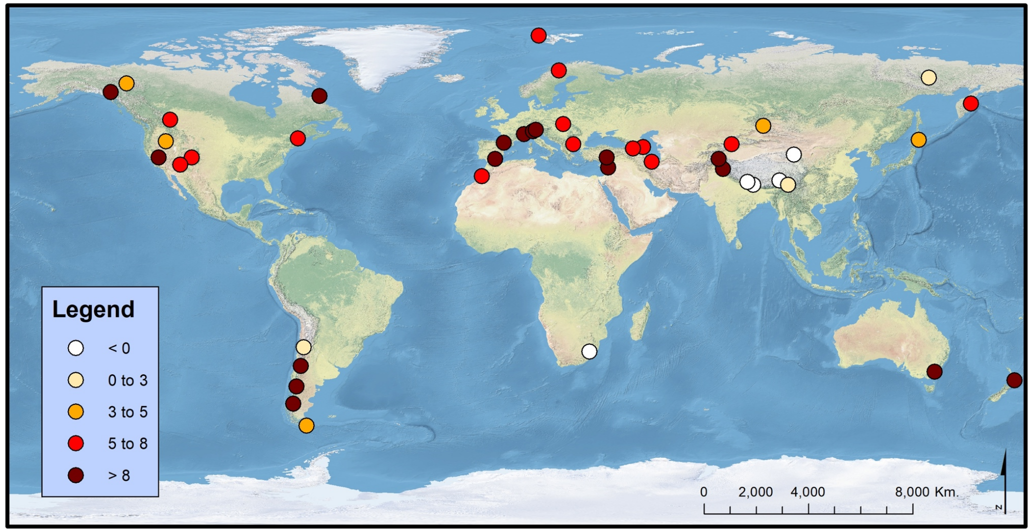


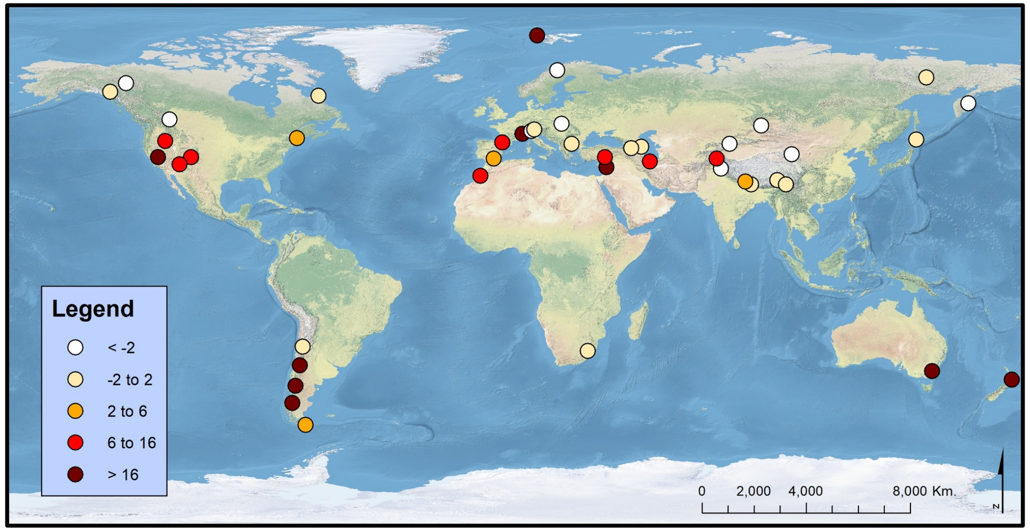
Hydrological sensitivity



Ratio Snowmelt/Qannual

D50

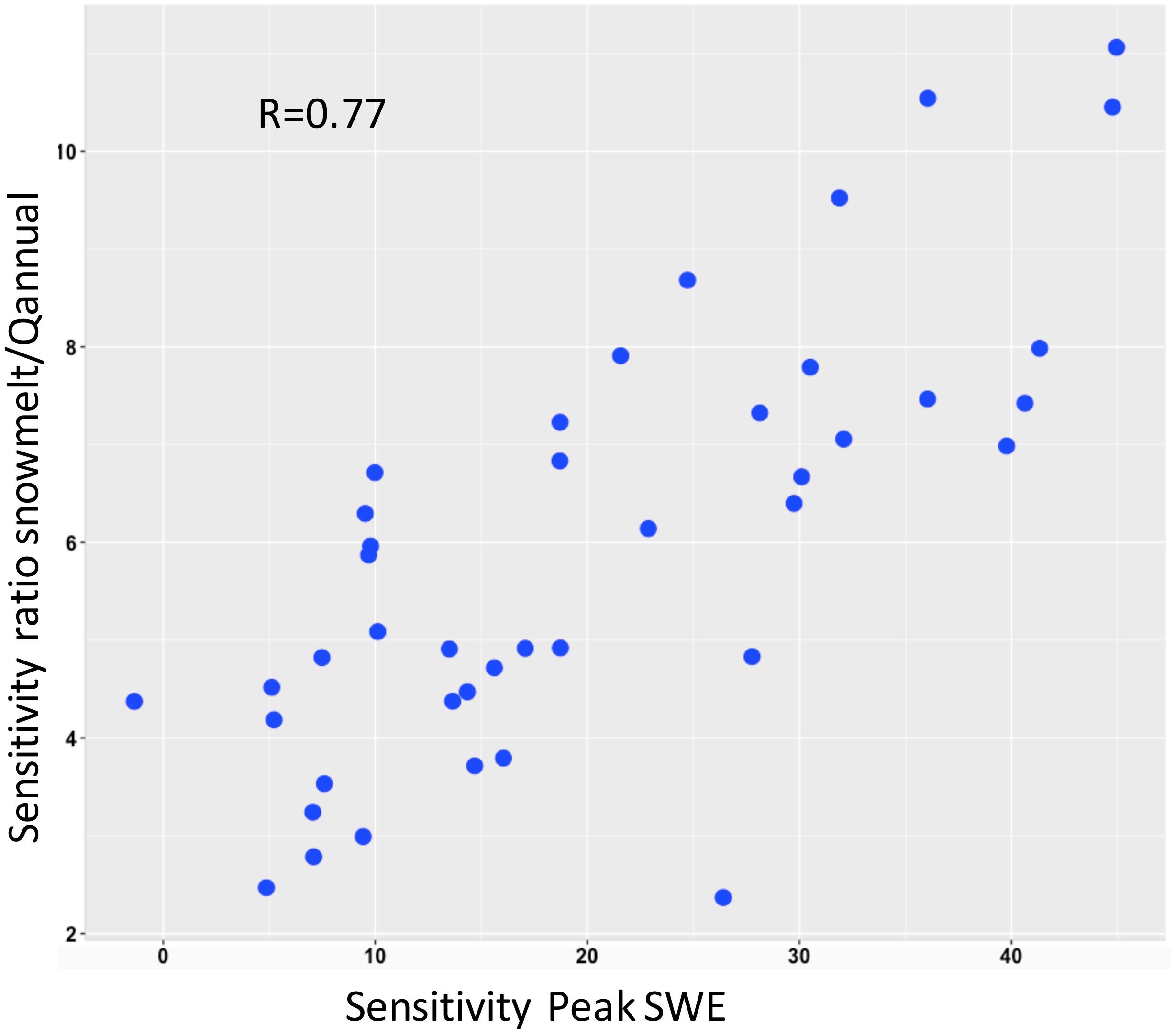


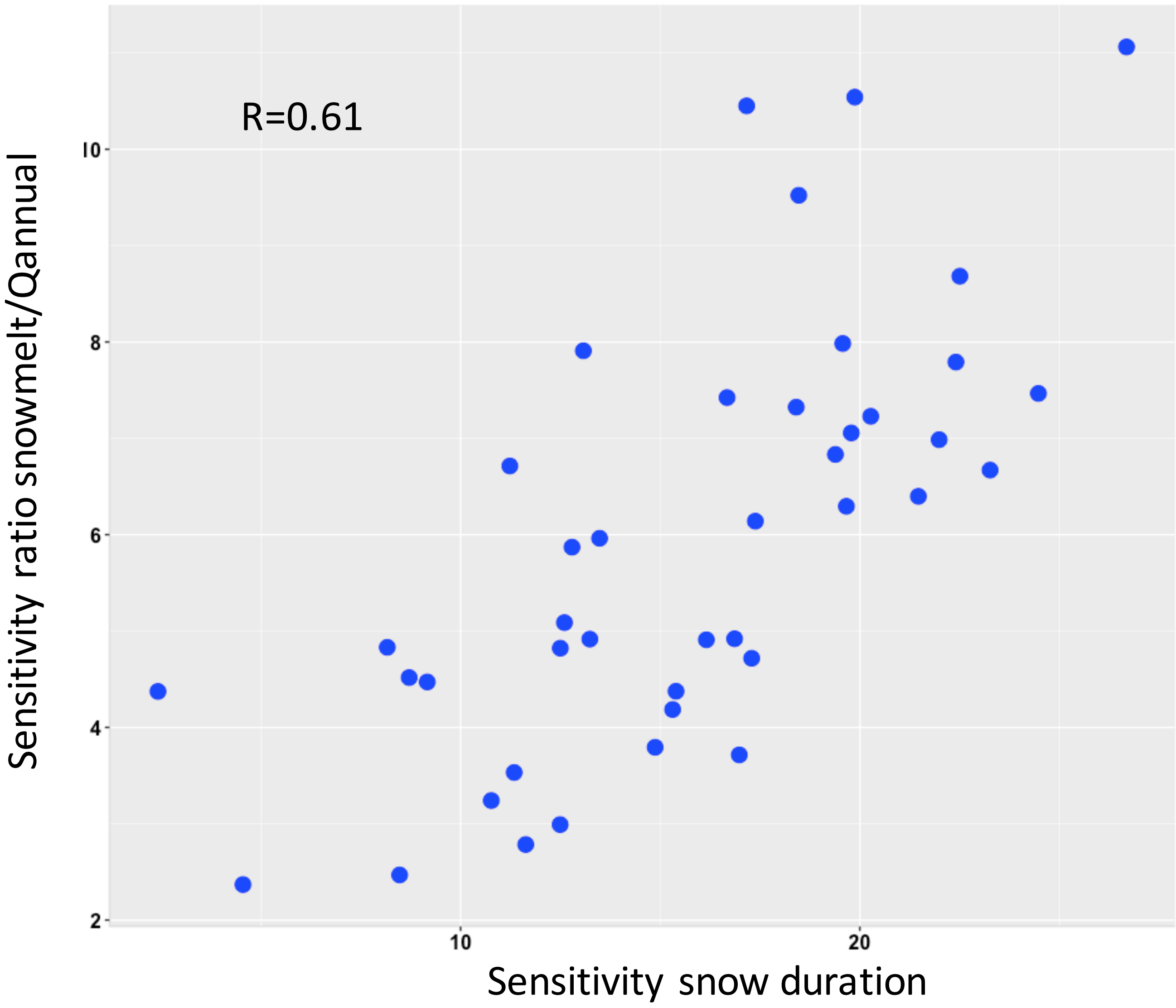


Snow damming

Hydrological sensitivity

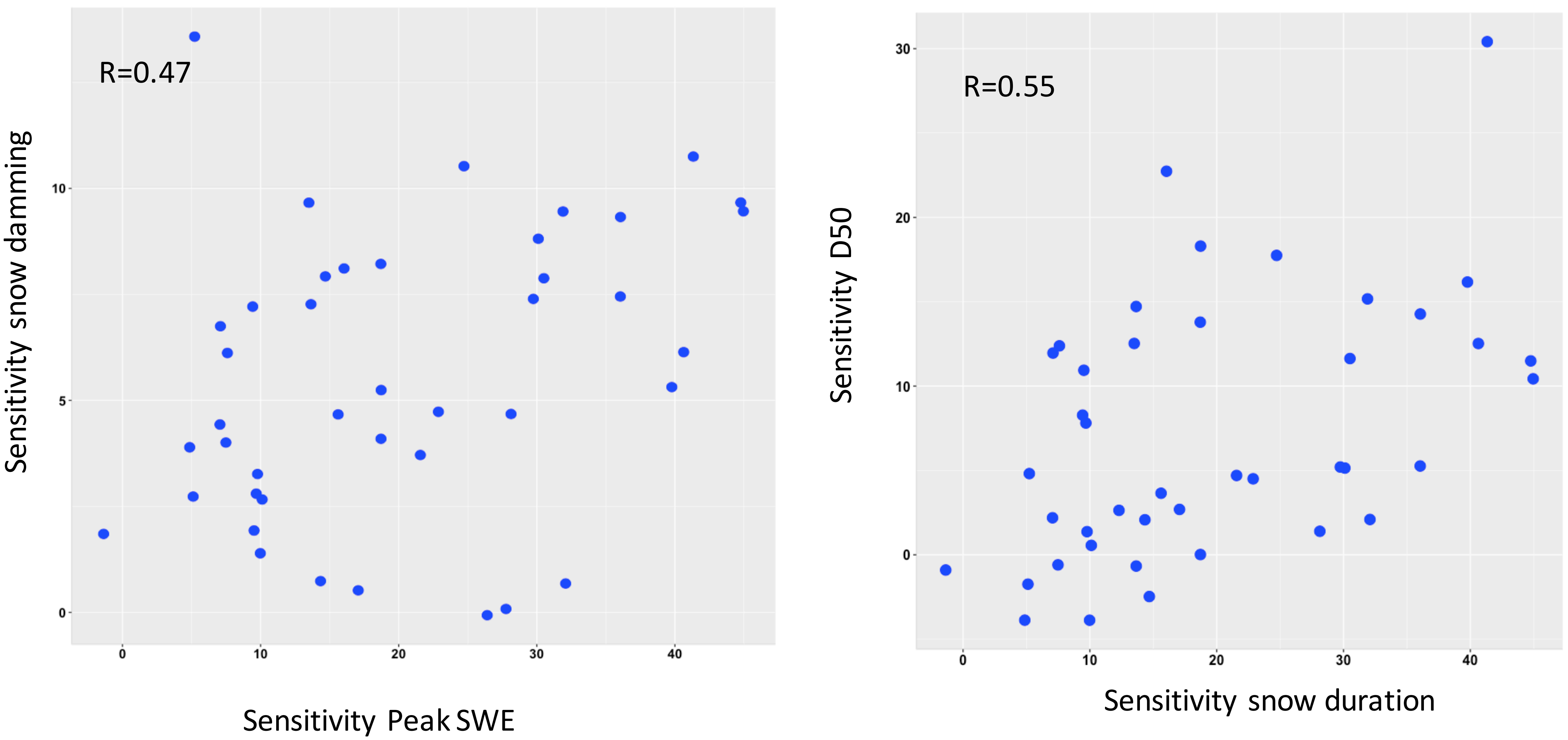
Sensitivity of snowmelt/Qannual *versus* sensitivity SWE peak and snow duration





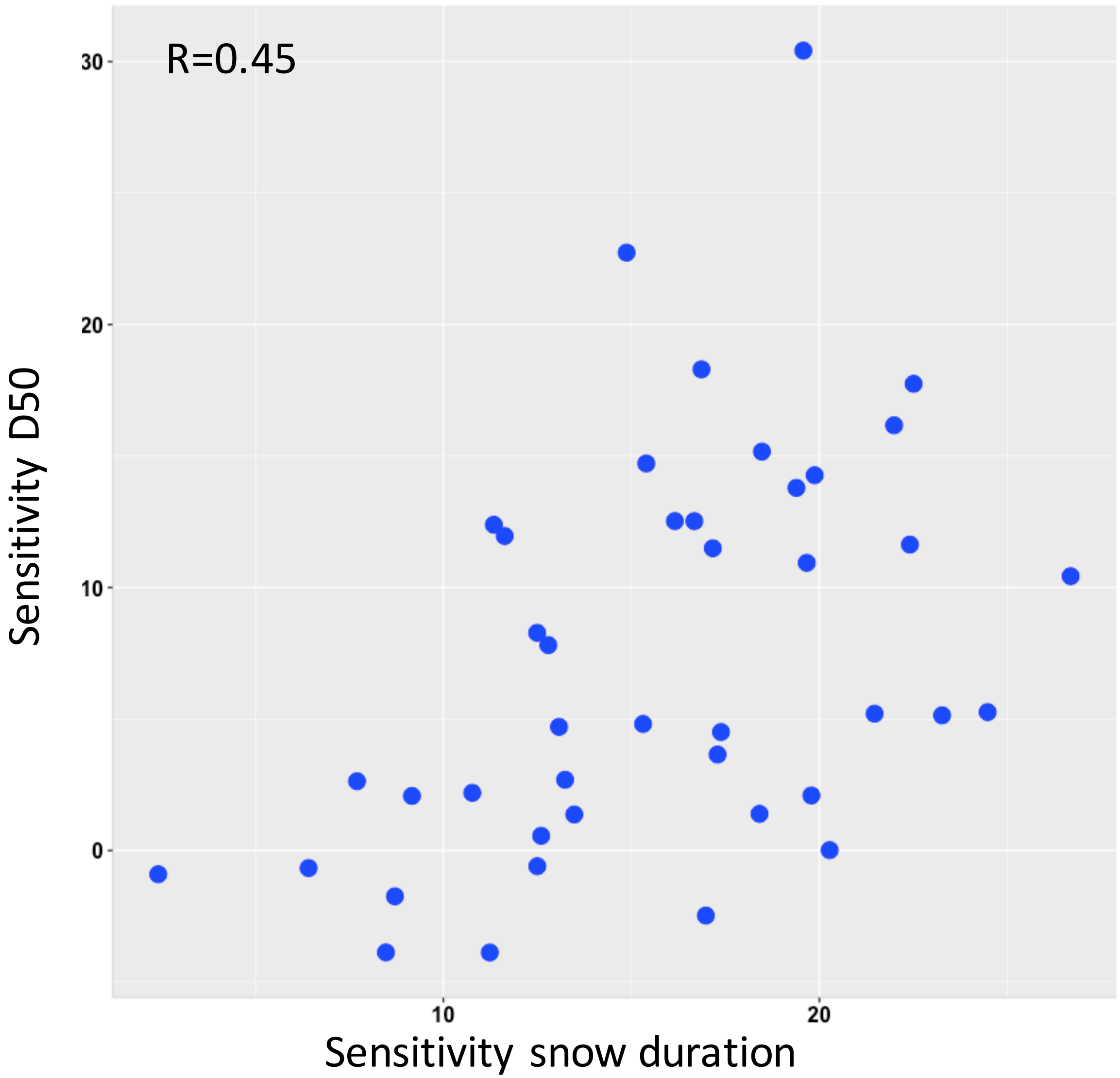
Hydrological sensitivity

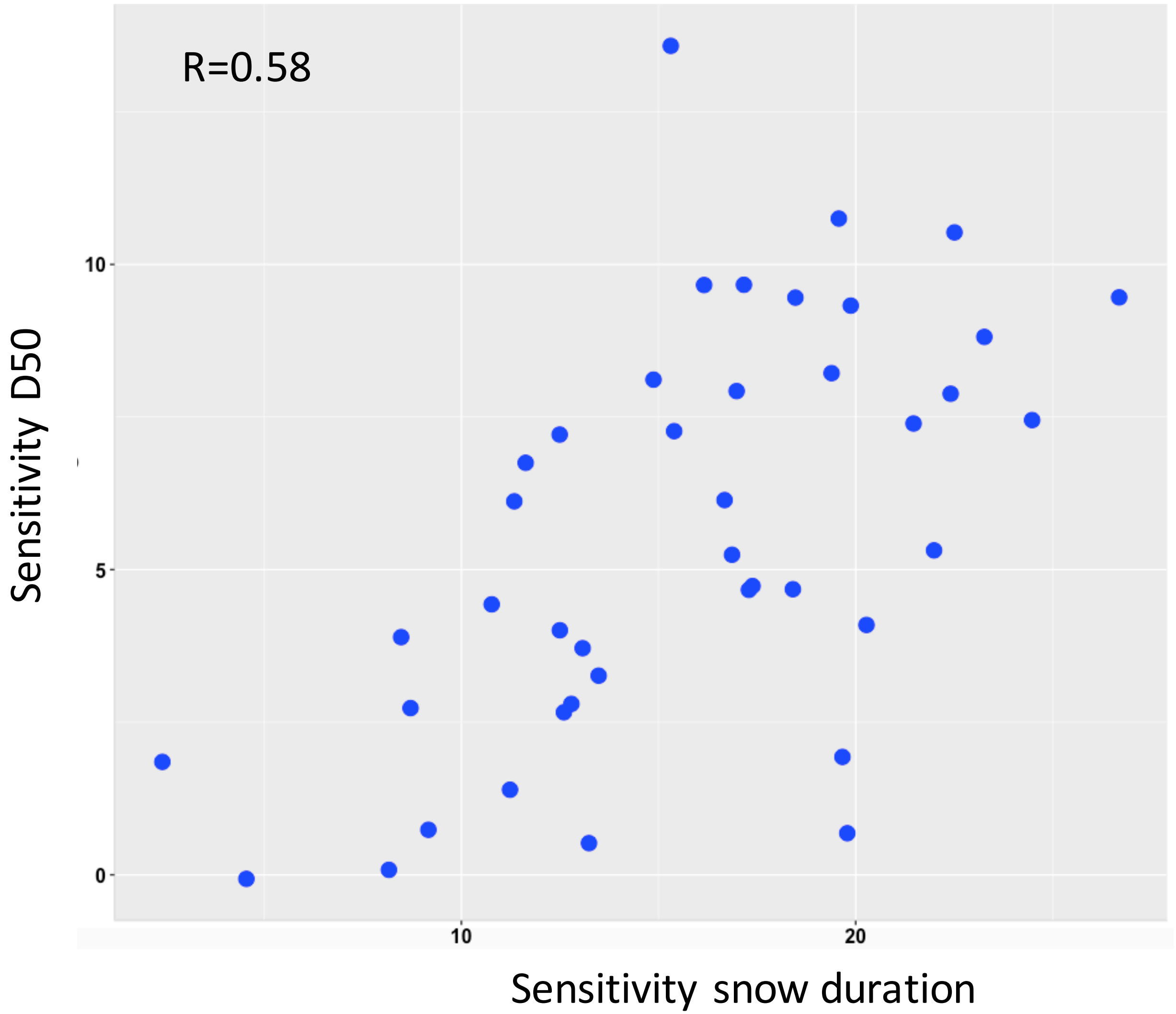
Sensitivity of Snow damming *versus* sensitivity SWE peak and snow duration



Hydrological sensitivity

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

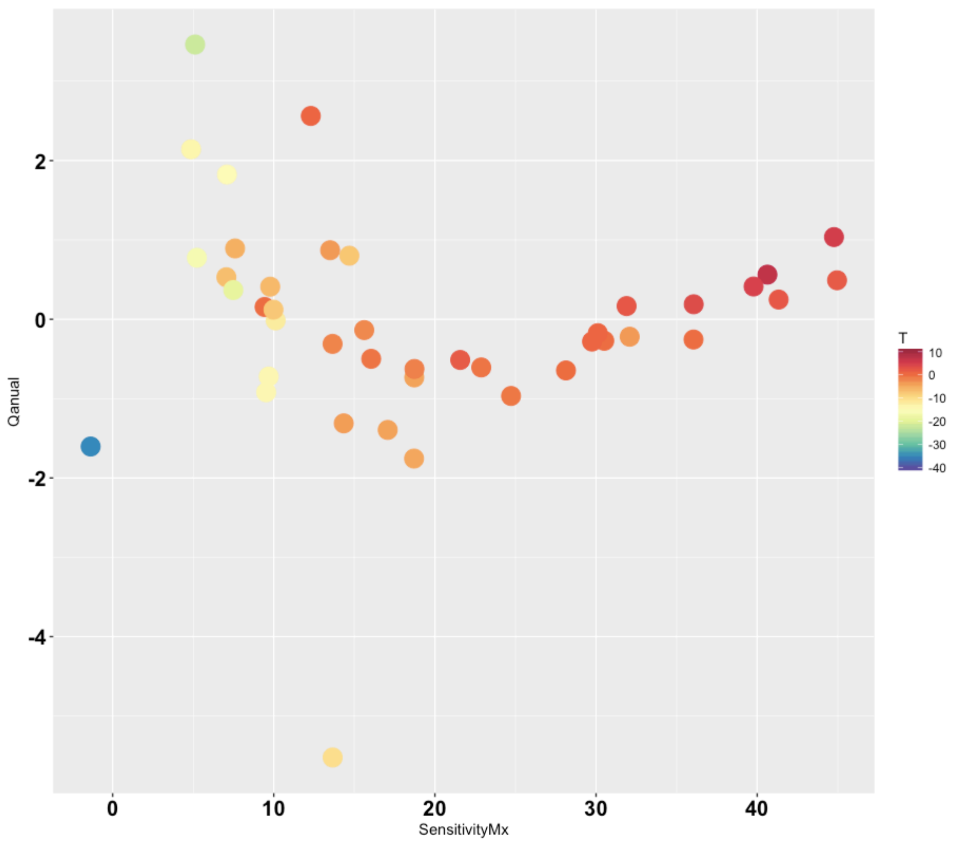




Hydrological sensitivity

Sensitivity of Qannual versus sensitivity SWE peak and snow duration

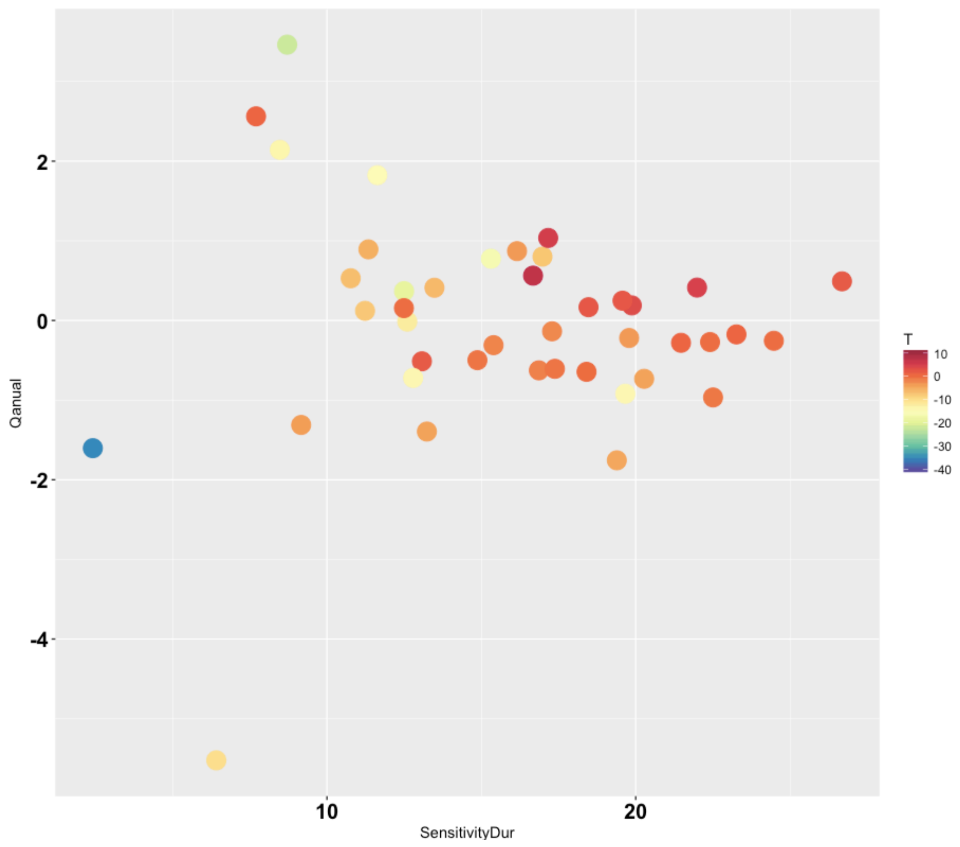
R=0.32



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

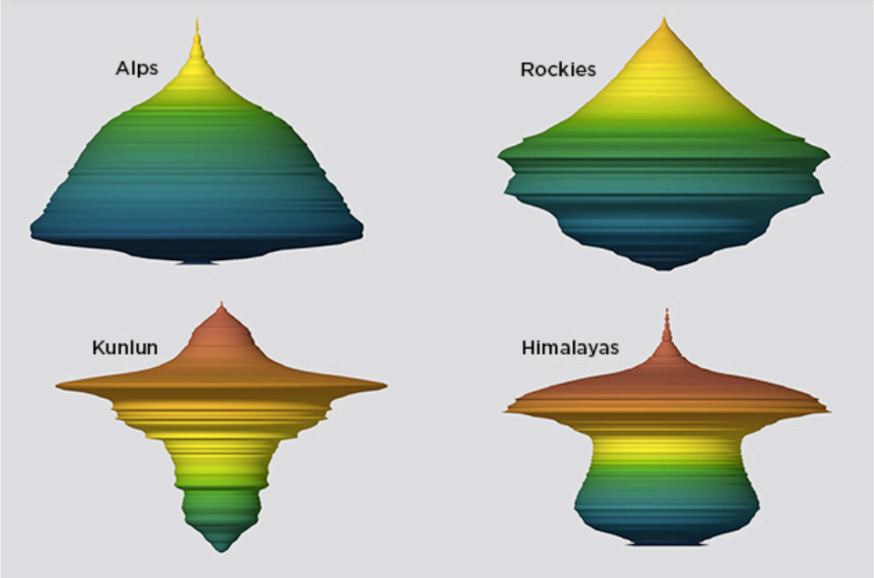
HYPSOMETRY MATTERS?

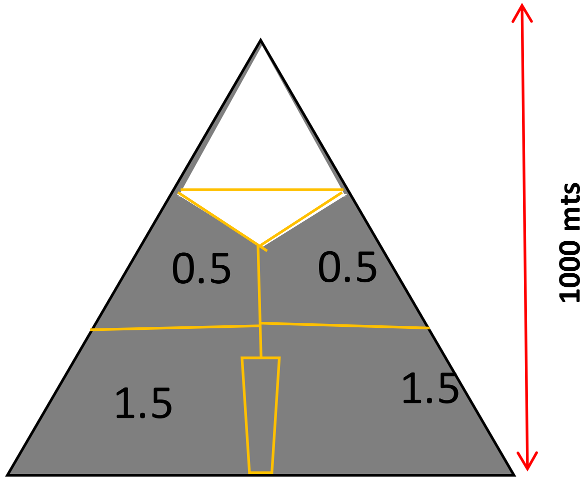
nature climate change

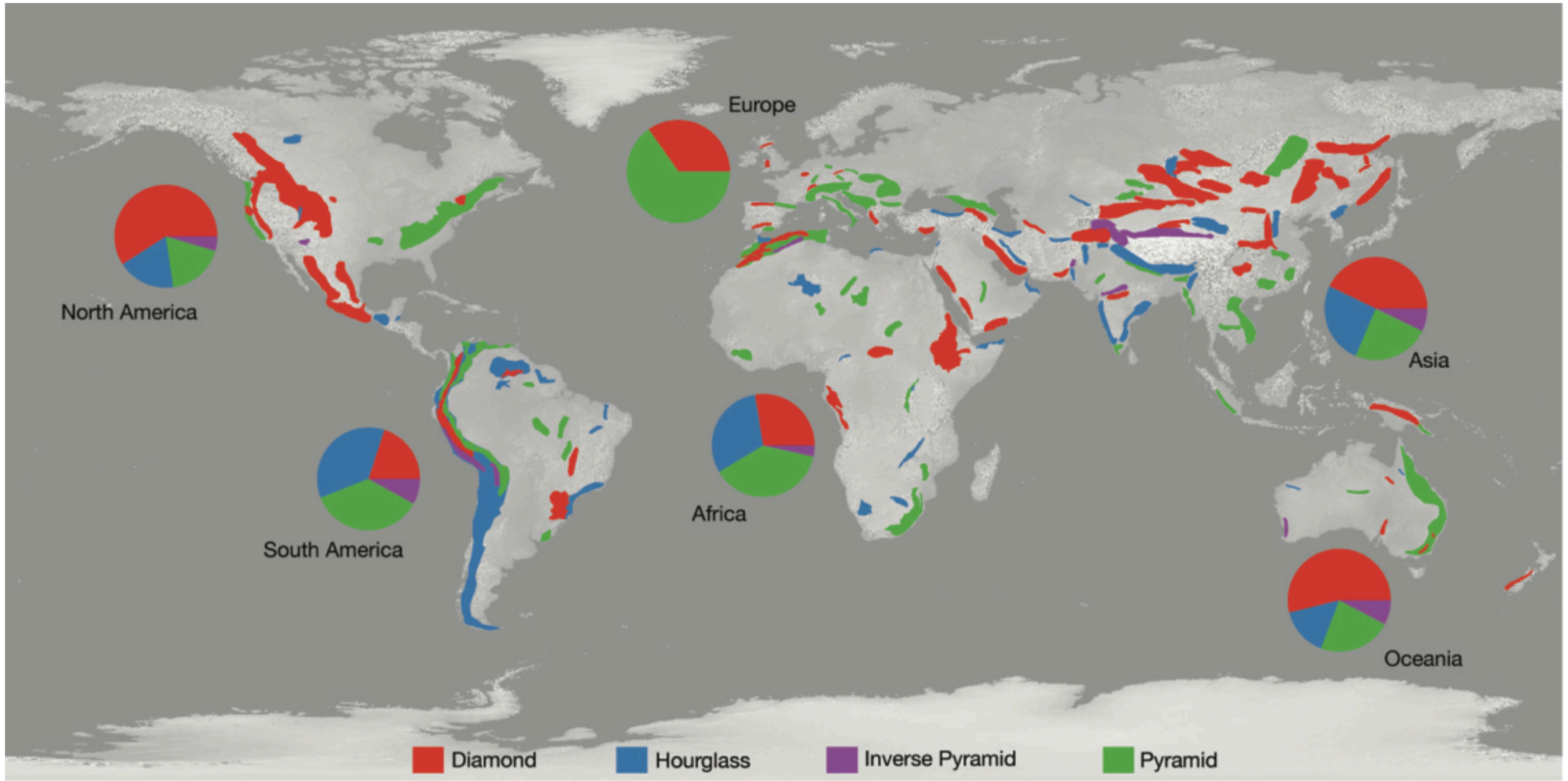
Letter | Published: 18 May 2015

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

Paul R. Elsen & Morgan W. Tingley







THANKS!!

Sensitivity of snowpack