IPROMO

PROGRAMME

MOUNTAINS IN A CHANGING CLIMATE: THREATS, CHALLENGES AND OPPORTUNITIES

28 SEPTEMBER - 9 OCTOBER 2020

Climate Change, water and hydropower issues in the mountains

Bocchiola, D.

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POLIMI & Climate change

2009-2020. IDRO-STELVIO. Una rete idrometrica per il Parco dello Stelvio, Finanziato da Parco Stelvio.

2010-2012. SHARE-Stelvio. Un Parco – Osservatorio per lo studio dei Cambiamenti Climatici e Ambientali in alta quota. Finanz. Regione Lombardia.

2010-2013. Share-Paprika. Effects of climate change on water resources in the Karakoram range (Pakistan, Asia). EVK2CNR

2010-2013. SEED, Social, Economic and Environmental Development for the realization of Central Karakorum National Park (CKNP). EVK2CNR

2011-2013. I-CARE. Impact of Climate change on Alpine water REsources: the case of Italy and Switzerland. 5x1000 Politecnico di Milano

2012. Programa plan de acción para la conservación de glaciares ante el cambio climático, DGA Cile

2014-2015: Khumbu Hydrology, monitoring and modeling hydrology of the Khumbu glacier and Dudh Koshi basin, Nepal. EVK2CNR

2014: ARARAT Expedition, 150 years of CAI.

2015-2016: POLIMI for KARAKORAM, 5x1000 Politecnico di Milano.

2017-2019 HERASE. Hydrogeological modeling for Erosion Risk Assessment from SpacE. Cariplo

2018-2020: Interdisciplinary Project for assessing current and expected Climate Change impacts on MOUntain PAstures (IPCC MOUPA). Cariplo

2019-2020 WWW.World.Water.Watch.The www of water, a proposed worldwide water watch. ASI.

2019-2022. GE.RI.KO. Mera. Gestione risorse idriche ed ambienti acquatici in comune – Il bacino del Fiume MERA. Interreg IT-CH, 2016.

2018-2021. Aval-Risk: Avalanche risk under present and prospective climate change: experimental modeling and mathematical models for risk mapping. Interdipartmental PhD Scholarship Call.

2019-2022. Assessment of hydrological flows in Lombardy alpine rivers, and their connection with the underground aquifer, under potential climate change scenarios in the XXI century. PhD Scholarship, 2019-2022. Funded by CAP.

Ongoing activities @ Polimi

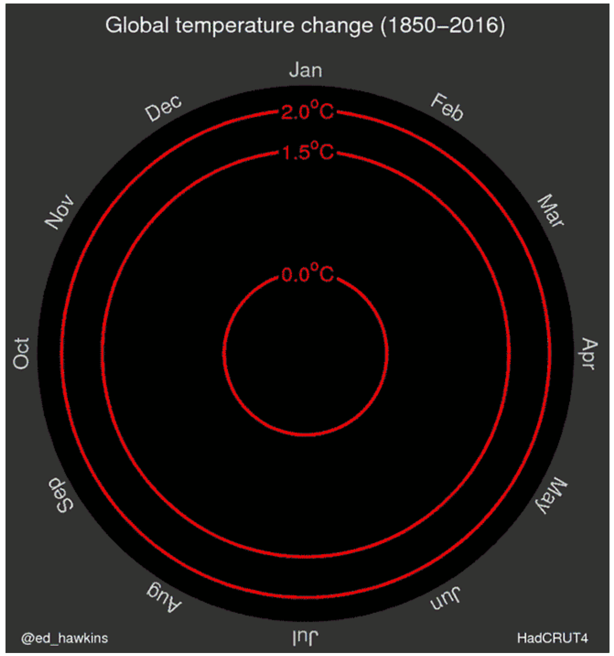
Climate-Lab

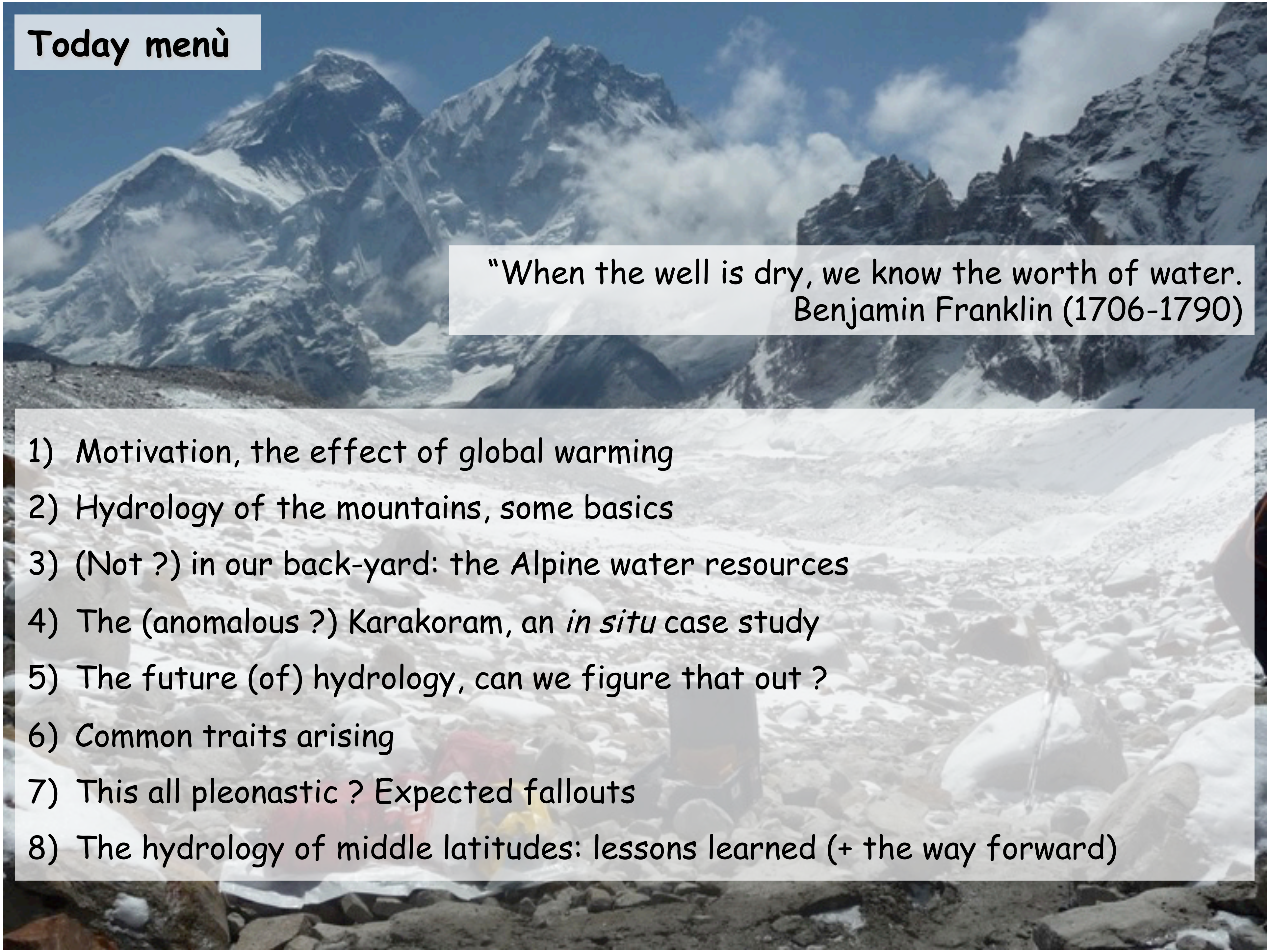
Interdipartmental Lab, call 2016, Depts DICA, DEIB, DASTU, ABC

Recently Politecnico di Milano joined CMCC Foundation (Centro Euro-Mediterraneo sui Cambiamenti Climatici), an institution with large experience in the field of climate/ocean/landscape modeling, and in general of climate change mitigation, and adaptation.
Climate-LAB mission is to (contribute to) initiate a cooperation in this area between Polimi personnel (Depts.) working in the field of climate change, and with CMCC

Scientific purpose:

1) Monitoring of key variables/processes at urban, regional, basin scale;
2) Providing services for those interested in climate change impact assessment.





Today menù

“When the well is dry, we know the worth of water.
Benjamin Franklin (1706-1790)

1) Motivation, the effect of global warming
2) Hydrology of the mountains, some basics
3) (Not ?) in our back-yard: the Alpine water resources
4) The (anomalous ?) Karakoram, an *in situ* case study
5) The future (of) hydrology, can we figure that out ?
6) Common traits arising
7) This all pleonastic ? Expected fallouts
8) The hydrology of middle latitudes: lessons learned (+ the way forward)

Motivation

Global warming has important consequences for the hydrological cycle, especially in temeperate areas, where water supply depends upon the cryospheric hydrology. **With more than one-sixth of the Earth's population relying on glaciers and seasonal snow packs for their water supply**, the consequences of these hydrological changes for future water availability regions are likely to be severe.

Barnett *et al.*, 2005, Nature 438, 303-309.

Kaser et al. (2010) e.g. introduced PIX index, i.e. resident population times share of streamflows from ice melt for a number of rivers. Five out of the first eight rivers in the rank are from HinduKush, Karakoram, and Himalaya, HKH (Aral lake, Amu-Darya and Syr-Darya, Indus, Ganges, Yangtze, Brahmaputra).

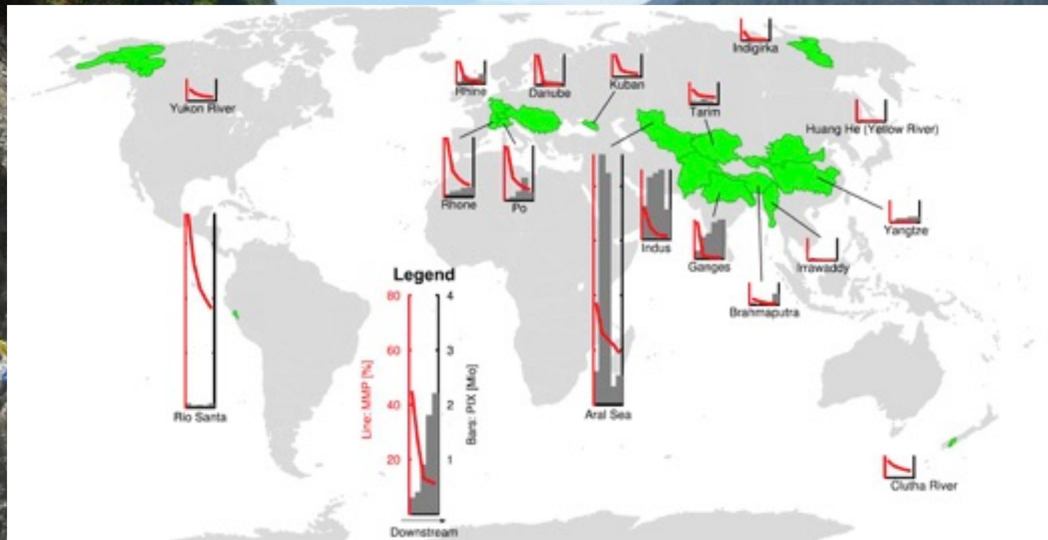


Table 1. Climatological and geographical characteristics of the river basins shown in Figs. 1 and 2, sorted by the PIX

Basin name	Basin area, km²	Glacier area, km²	Glacier area, %	Population, 10^6	PIX, 10^6
Aral Sea	1,234,075	11,319	0.92	41.01	10.29
Indus	1,139,814	20,325	1.78	211.28	4.82
Ganges	1,023,609	12,659	1.24	448.50	2.40
Po	73,297	818	1.12	16.55	0.81
Rhone	97,702	1,162	1.19	10.12	0.57
Rhine	190,713	459	0.24	59.07	0.52
Yangtze	1,746,593	1,895	0.11	383.04	0.37
Brahmaputra	527,666	16,118	3.05	62.43	0.31
Danube	794,133	617	0.08	81.38	0.31
Tarim	1,053,180	20,494	1.95	9.22	0.30
Rio Santa	11,901	503	4.23	0.57	0.27
Kuban	59,120	215	0.36	3.45	0.05
Huang He	988,702	172	0.02	162.70	0.02
Indigirka	341,577	338	0.10	0.04	0.00
Irrawaddy	410,376	25	0.01	35.26	0.00
Yukon River	830,257	9,070	1.09	0.13	0.00
Clutha River	17,182	147	0.86	0.03	0.00

PO river !!!!


PNAS

Contribution potential of glaciers to water availability in different climate regimes

Georg Kaser, Martin Großhauser, and Ben Marzeion[1]

Institut für Geographie, Universität Innsbruck, Innrain 52, 6020 Innsbruck, Austria

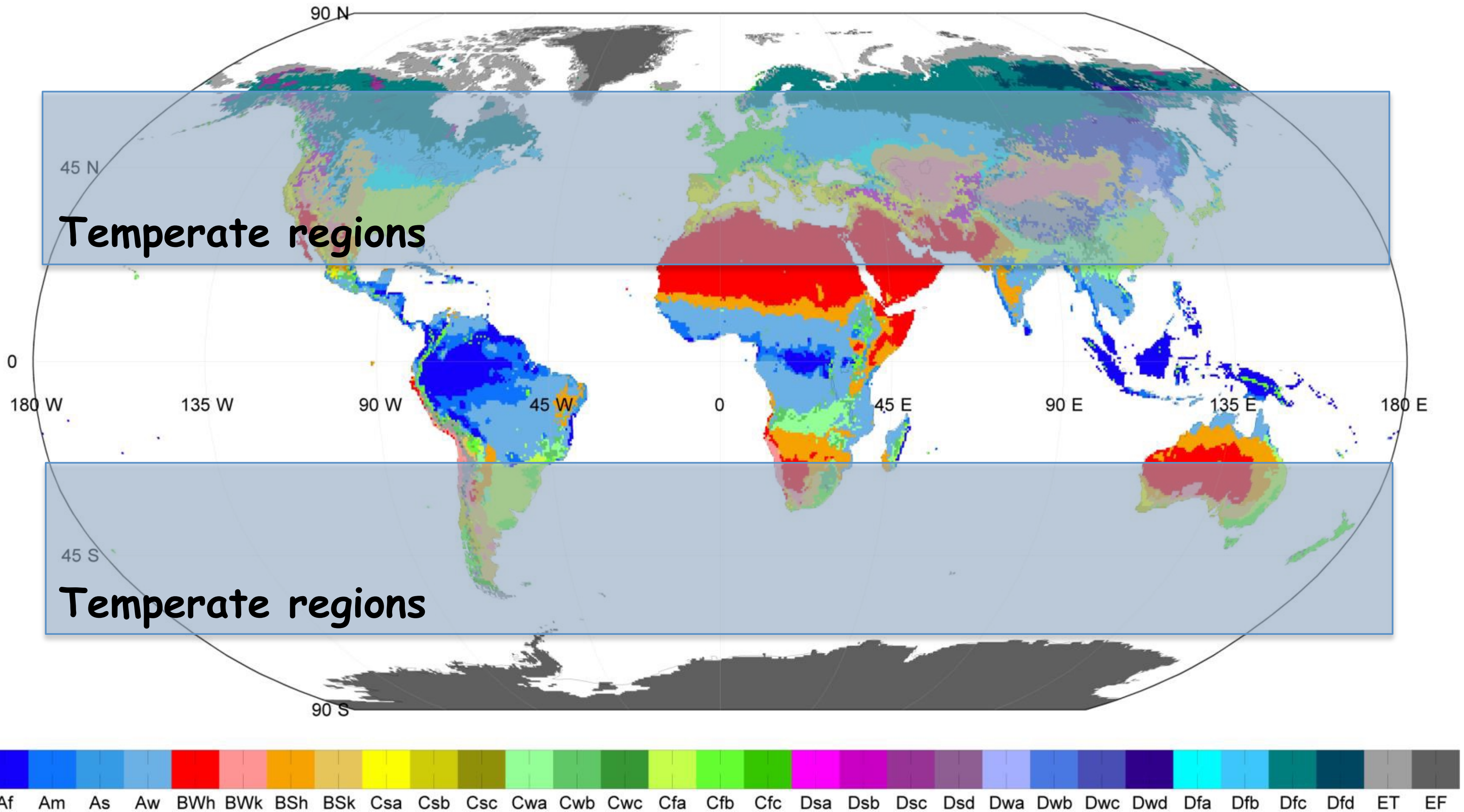
Edited by Roger G. Barry, University of Colorado, Boulder, CO, and accepted by the Editorial Board October 12, 2010 (received for review June 11, 2010)

Although reliable figures are often missing, considerable detrimental changes due to shrinking glaciers are universally expected for water availability in river systems under the influence of ongoing global climate change. We estimate the contribution potential of seasonally delayed glacier melt water to total water availability in large river systems. We find that the seasonally delayed glacier

periods in a region coincide, the production of melt water and the increase of water storage occur at the same time, reducing the effect of seasonally delayed water release from the glaciers. The relative impact of glacier melt during wet and warm periods is further decreased through the general increase in water availability from precipitation.* Therefore, melt water runoff matters

Mountain hydrology

World map of Köppen climate classification for 1901–2010



First letter	Second letter		Third letter
A: Tropical	f: Fully humid	T: Tundra	h: Hot arid
B: Dry	m: Monsoon	F: Frost	k: Cold arid
C: Mild temperate	s: Dry summer		a: Hot summer
D: Snow	w: Dry winter		b: Warm summer
E: Polar	W: Desert		c: Cool summer
	S: Steppe		d: Cold summer

Data source: Terrestrial Air Temperature/Precipitation: 1900-2010 Gridded Monthly Time Series (V 3.01)

Resolution: 0.5 degree latitude/longitude

Website: http://hanschen.org/koppen

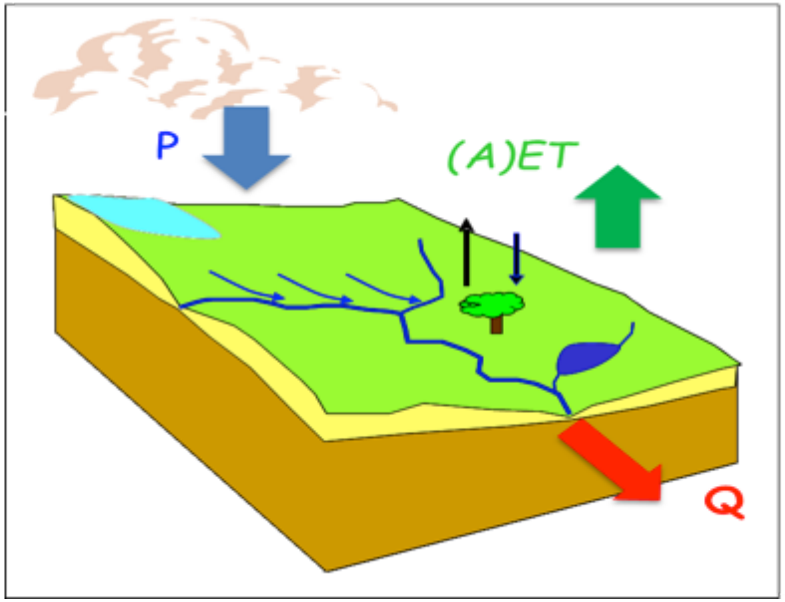
Ref: Chen, D. and H. W. Chen, 2013: Using the Köppen classification to quantify climate variation and change: An example for 1901–2010. Environmental Development, 6, 69-79, 10.1016/j.envdev.2013.03.007.

Hydrology in temperate climates, some basics

The water budget, in one "average" year

S= soil water content
P= total precipitation (rain and snow)
R= Rainfall
M_s= snow melt
ET= evapotranspiration
Q= stream flow

$$S^{t+\Delta t} = S^t + R + M_s - ET - Q$$



For large/closed catchments and long duration, e.g. yearly mean

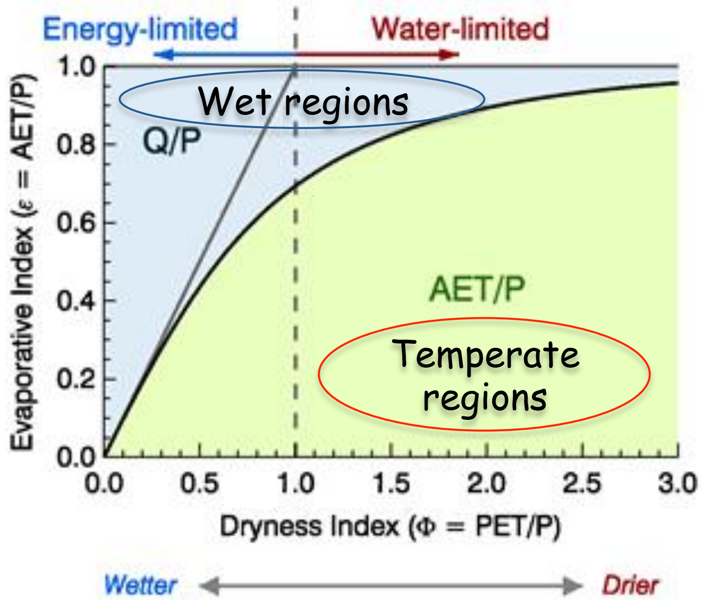
Precipitation is «used» for steam flow, and evapotranspiration (by vegetation)

$$P = (A)ET + Q$$

Evapotranspiration has a maximum (potential) value, depending (largely) on temperature, called *PET*, or *ETP*

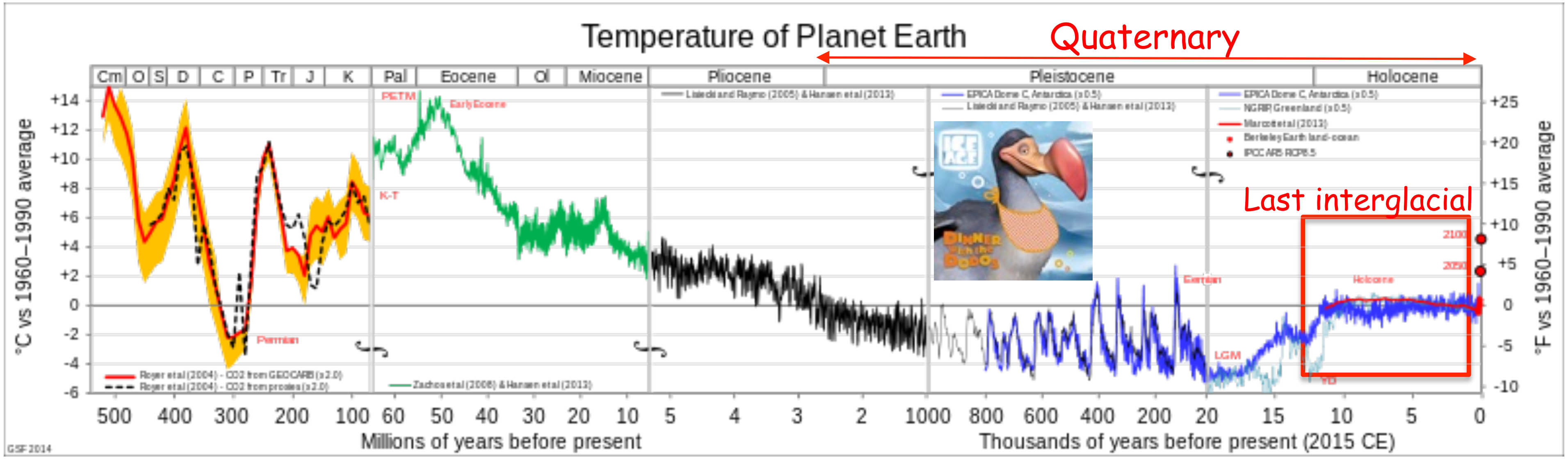
$$(A)ET = \Phi PET(T)$$
$$\Phi \leq 1$$

$$Q = P - (A)ET = P\left(1 - \frac{AET}{P}\right) = P(1-\varepsilon) = \frac{PET}{\Phi}(1-\varepsilon)$$



Budyko curve (1974)

Mountain and glaciers in the Quaternary: our water towers



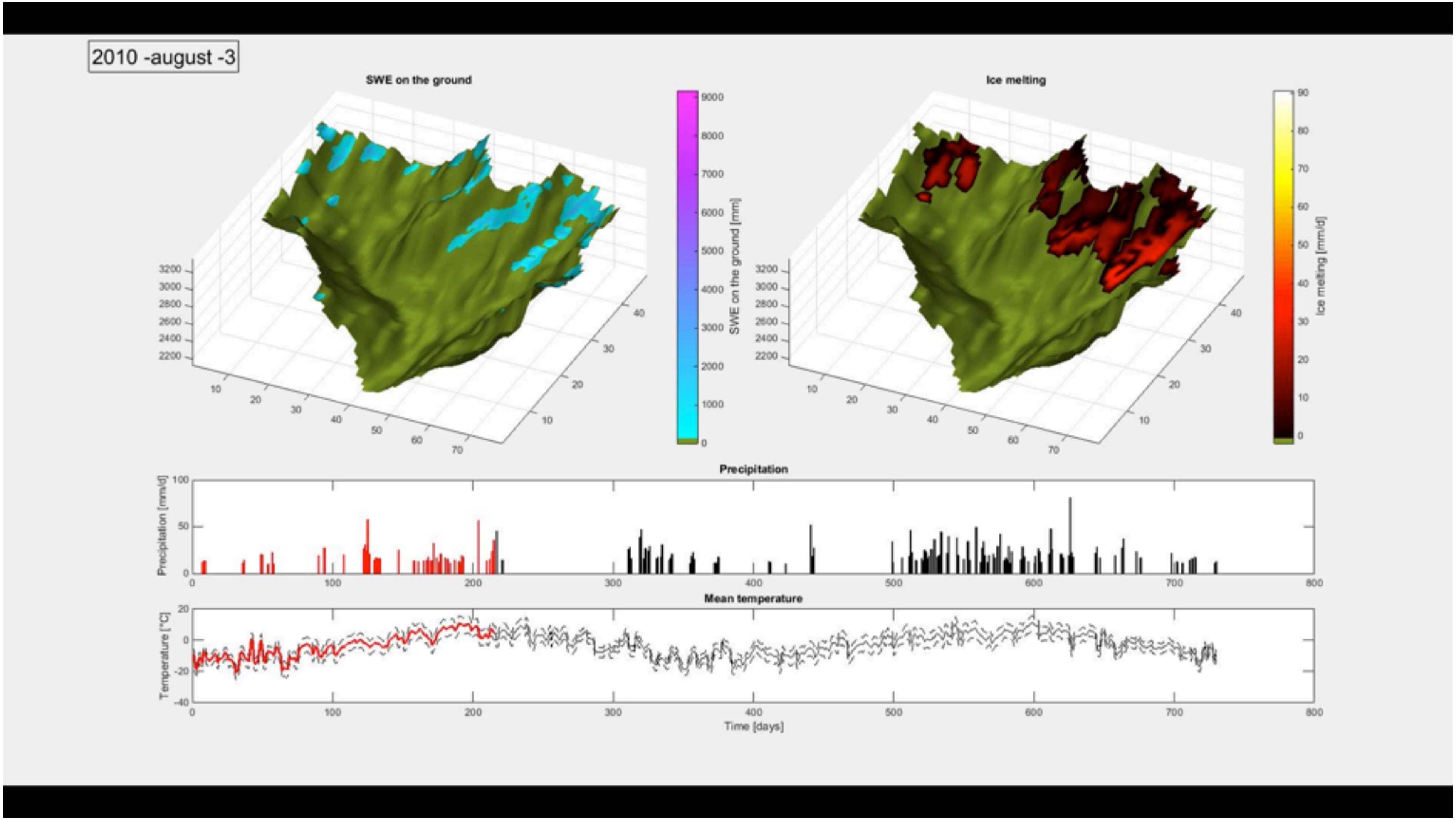
In temperate (semi-arid to arid) regions, glaciers in the high altitude provide an extra source of water by ice melt

$$P = (A)ET + Q + M_i$$

Mountain hydrology, some basics

Hydrology in the cryospheric areas

Dosdè Movie



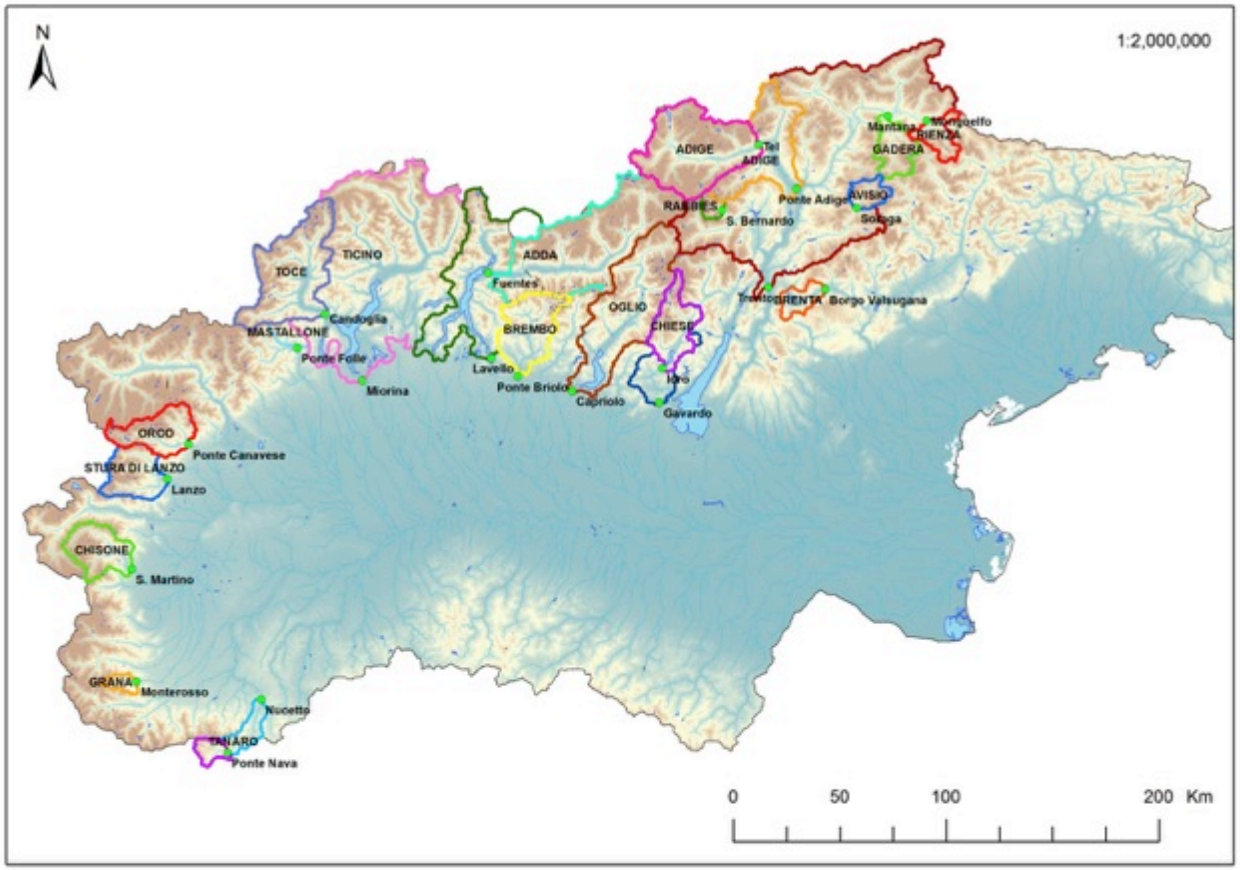
The animation displays (bottom panel) daily measured temperature, and total precipitation (at 2000 asl), and subsequent snow accumulation (top, left), and ice melting (top, right) in the Dosdè glacier (high Valtellina, Italy) during 2010-2011.

(Not ?) in our back-yard: the Alpine water resources

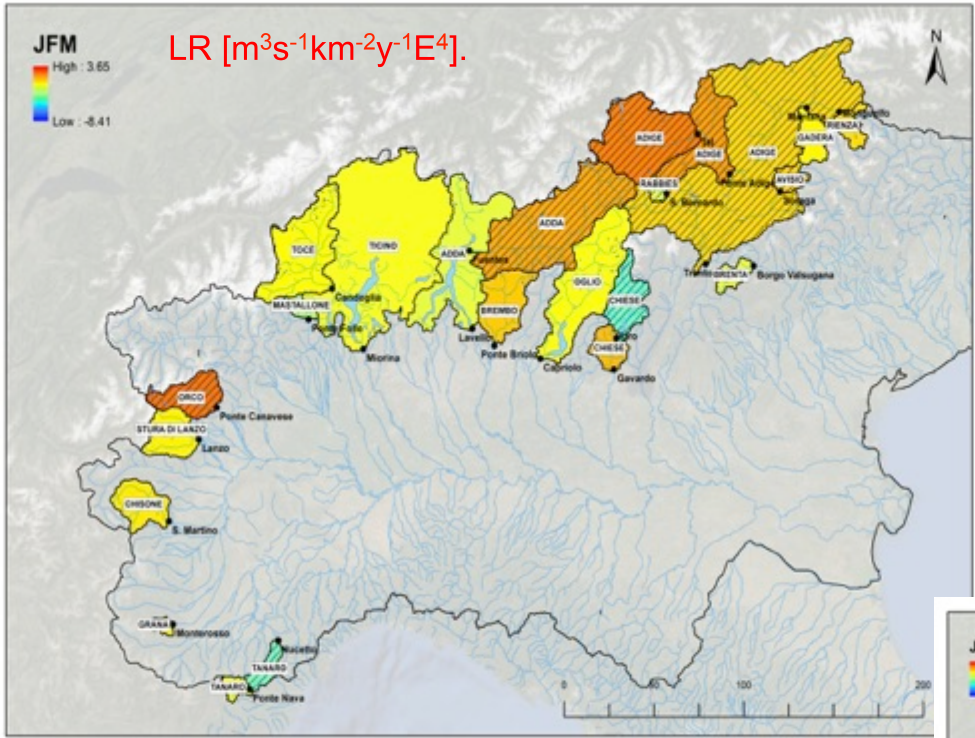
Question(s)

1) Did hydrological cycle change in Italian catchments lately ?
2) Drivers of this change ?
3) The potential future ?

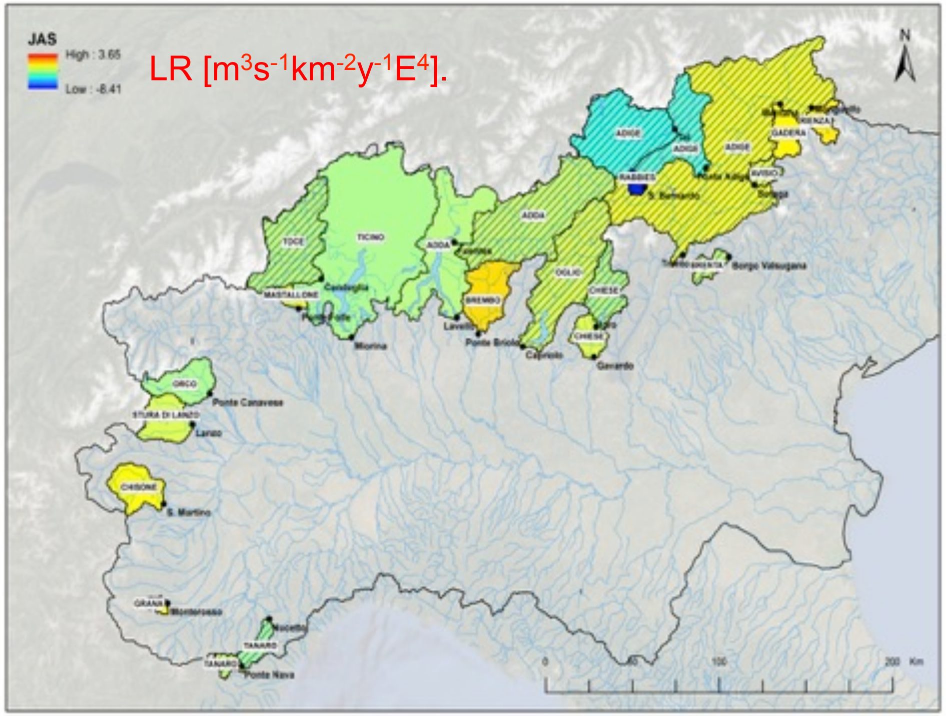
We sistematically investigated long term (1921-2011, with variable length of data series) changes of yearly and seasonal discharges of 23 Alpine rivers in Northern Italy, to evidence non stationarity, and trends using linear regression, and Mann Kendall test, traditional and progressive.



In short



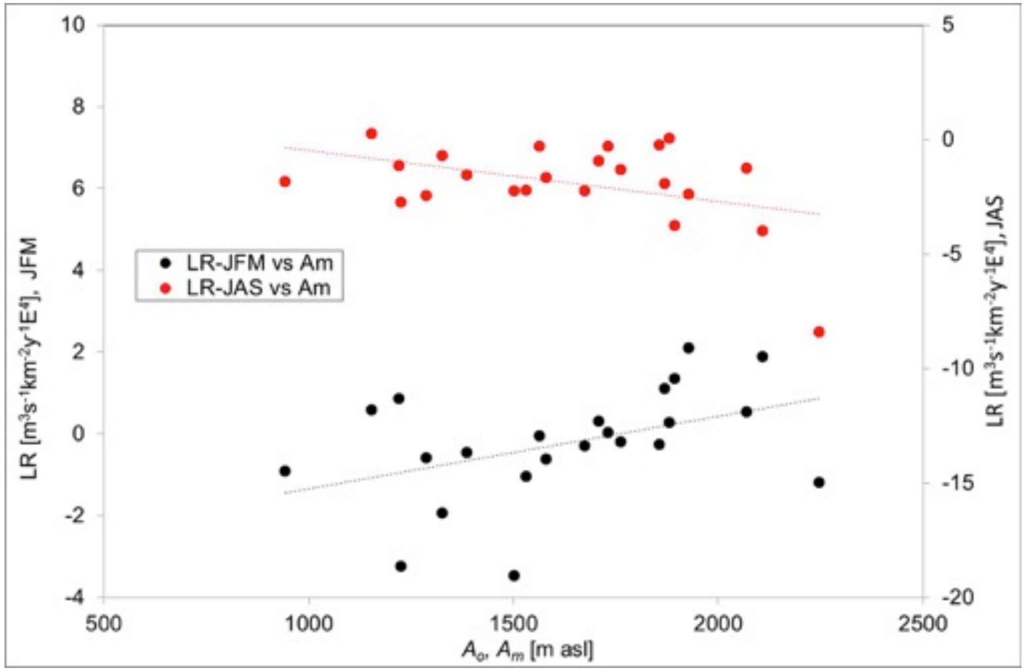
For specific (i.e. per contributing area) <u>winter decrease is seen below 1800 m asl or so, while increase is found above</u>, and the more Northern the larger the increase. Specific discharges during spring mostly decrease in time, and more so for increasing outlet altitude, while <u>summer specific discharges always decrease</u>, and more notably with increasing altitude of the contributing catchment.

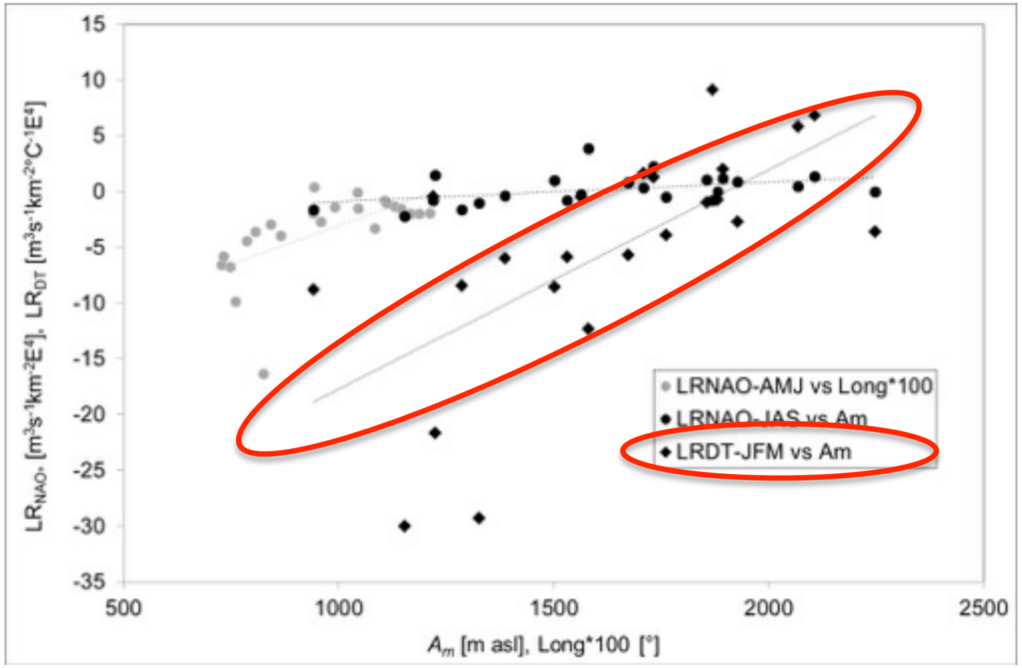


Hydrological changes in the Alpine stream water resourcess

REGULATION ?????

Drivers ?





A_0 is outlet altitude
A_m is average altitude

NAO and global thermal anomalies DT are correlated against the rate of variation of hydrological fluxes, with the intensity of correlation linked to altitude and longitude. The observed trends may be explained by:

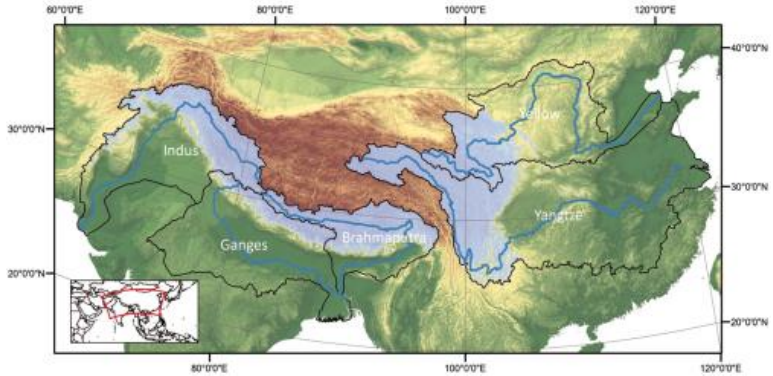
i) Trading of rainfall for snowfall during winter, resulting into larger flows, and affecting more highest catchments and Northern areas,
ii) Lack of snow cover at thaw, and shrinking of ice covered areas, decreasing melt water deliver during spring, and summer, more evident at the highest altitudes, and
iii) Increase of evapotranspiration driven by temperature, leading to increased soil moisture uptake and decreased in stream fluxes at the intermediate altitudes.

EDUCATED GUESS !!!!

Long is Longitude
NAO is northern atlantic oscillation
DT is global thermal anomaly

The (anomalous ?) Karakoram, an *in situ* case study

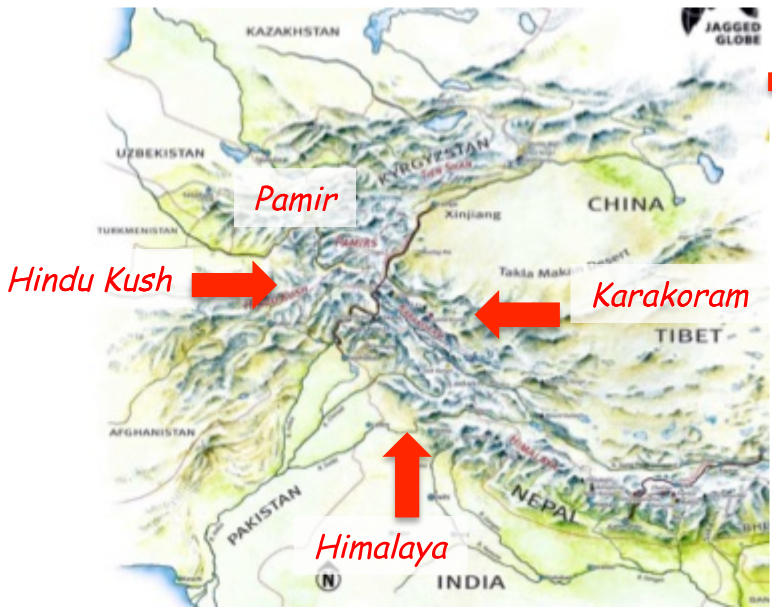
The mountain range of the Hindu Kush, Karakoram and Himalaya (HKKH) contains a large amount of glacier ice, and it is the *third pole* of our planet.
The Indo-Gangetic plain (IGP, including regions of Pakistan, India, Nepal, and Bangladesh) is challenged by increasing food production to feed increasing population

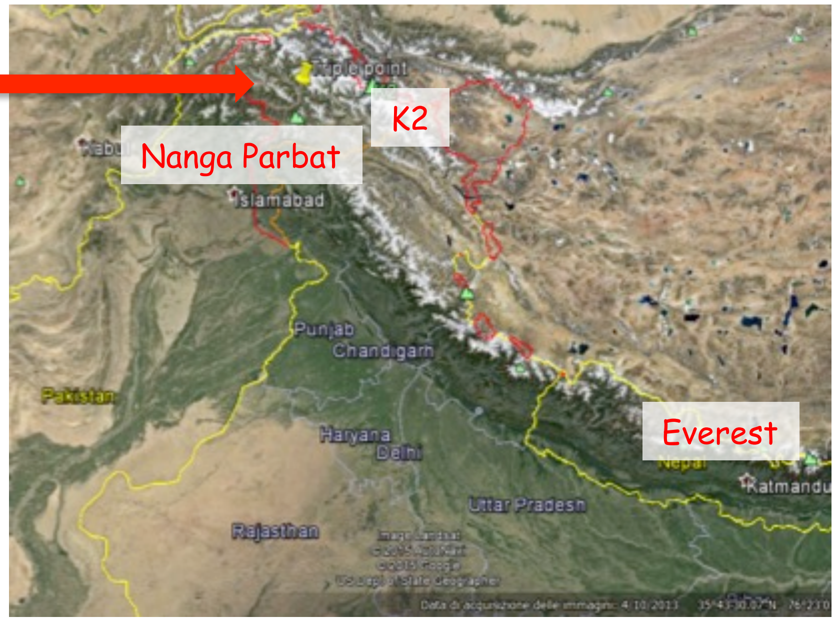


The "triple point"

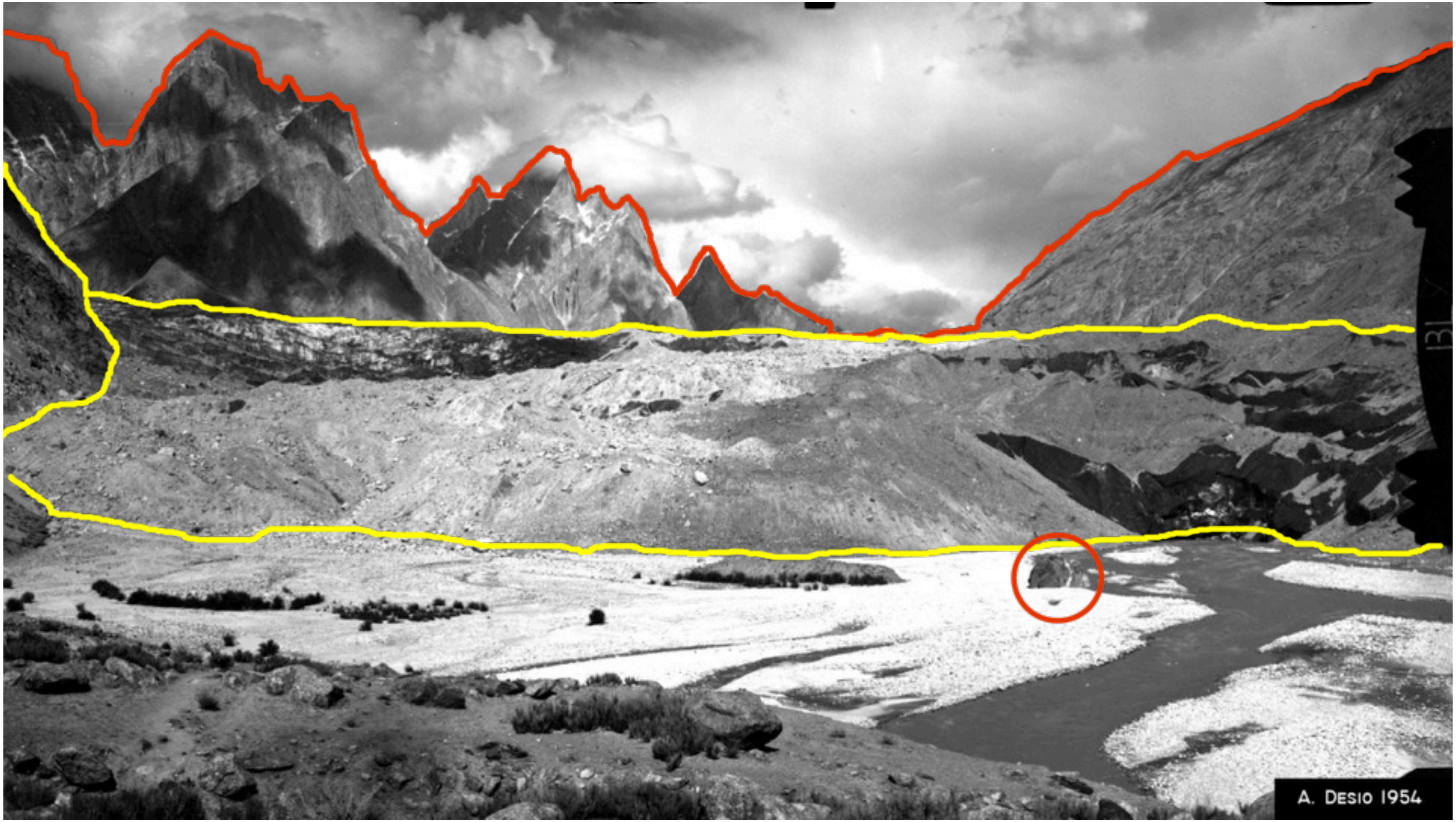
Latitude: 35°44'54.47"
Longitude: 74°37'45.98"

Backbones of Asian water towers





The Baltoro glacier, a steady one: 1954



The Baltoro glacier, a steady one: 2013

Case study: Shigar basin, PAKISTAN

The Shigar river basin

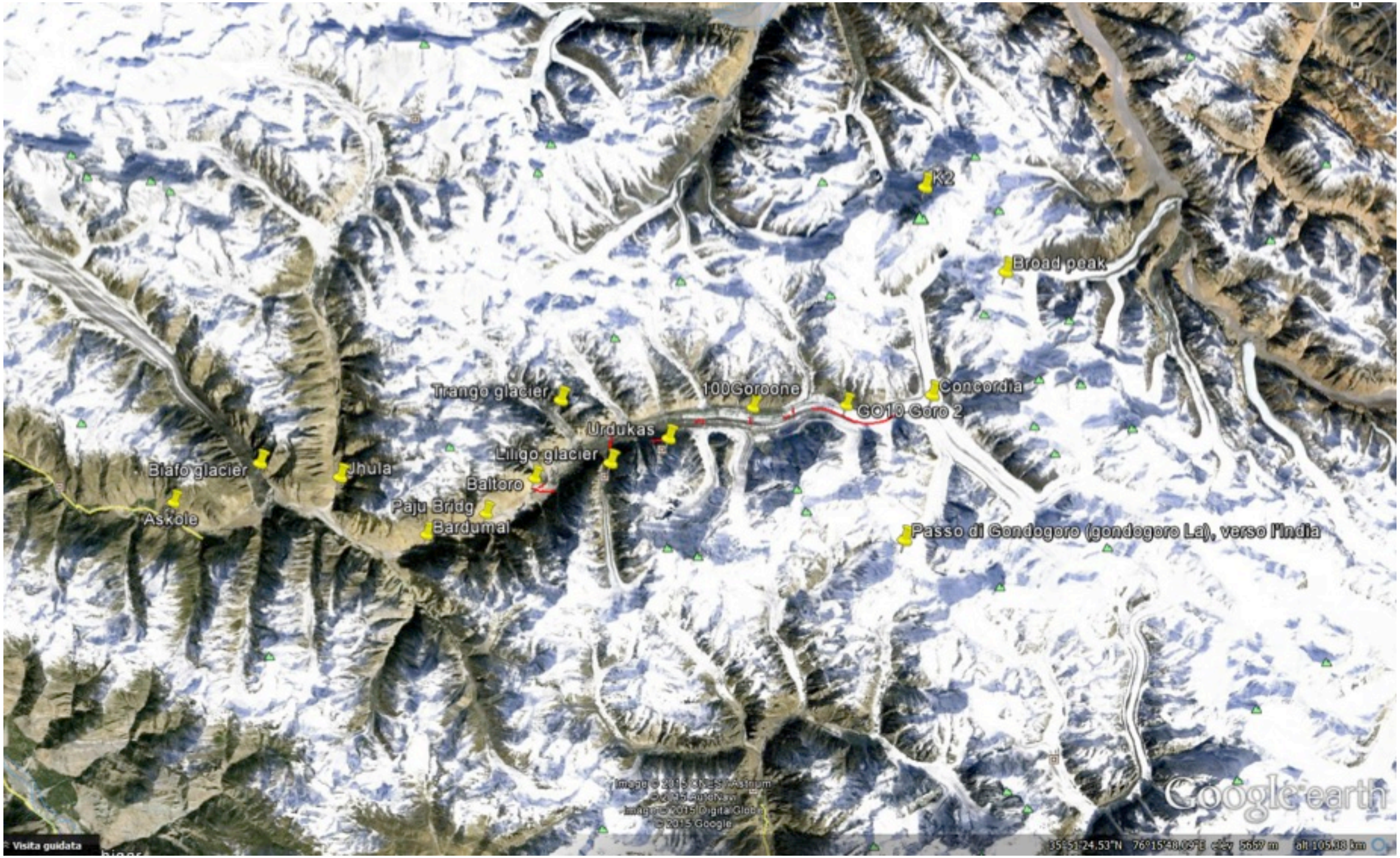
Projects

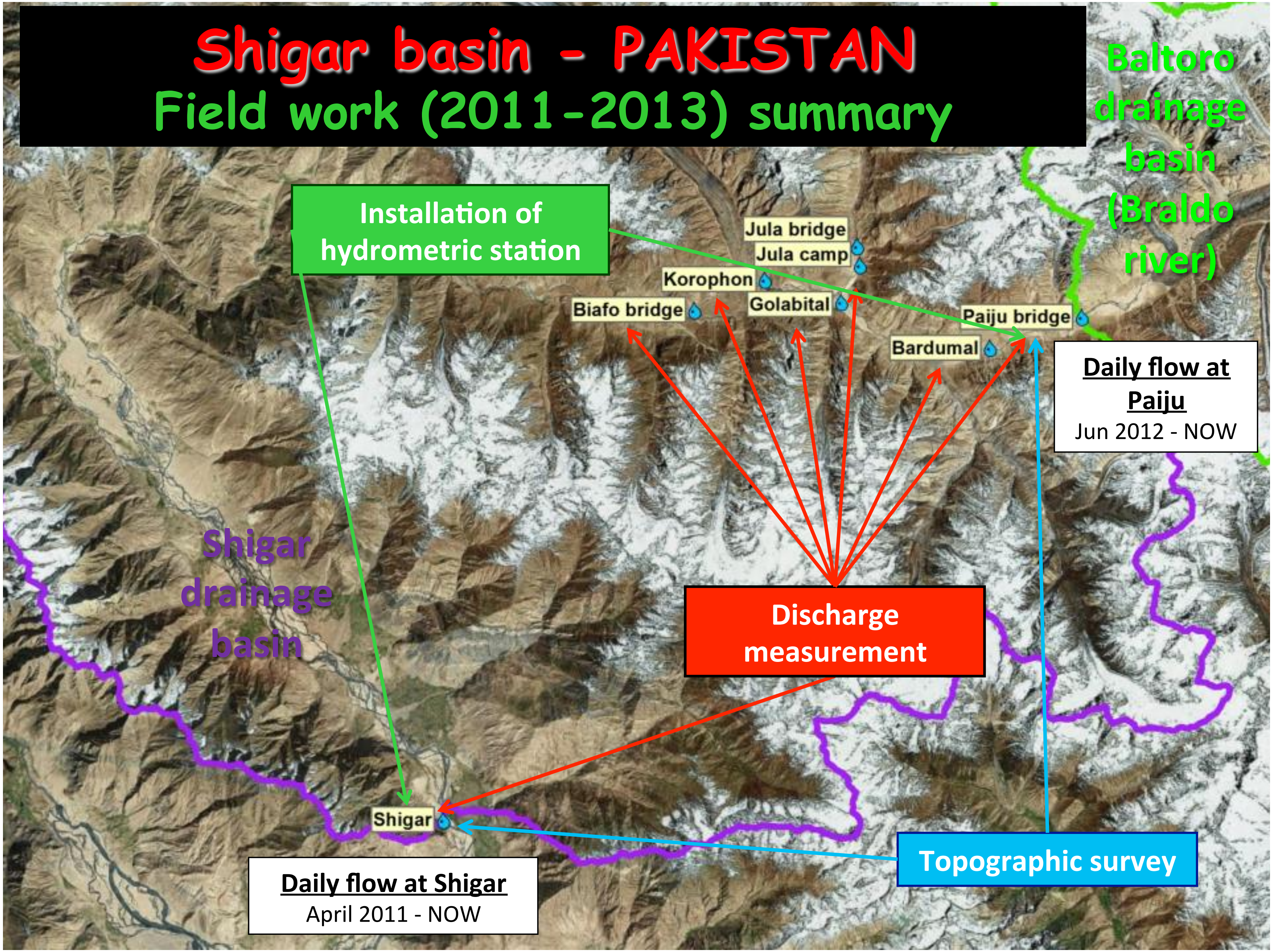
2010-2013. Share-Paprika. Effects of climate change on water resources in the Karakoram range (Pakistan, Asia). EVK2CNR

2010-2013. SEED, Social, Economic and Environmental Development for the realization of Central Karakorum National Park (CKNP). EVK2CNR

The K2 trek

Ca. 60 km, ca. 1 week, to Concordia, 4700 masl




Shigar basin - PAKISTAN
Field work (2011-2013) summary
Baltoro drainage basin (Braldo river)
Installation of hydrometric station
Jula bridge
Jula camp
Korophon
Biafo bridge
Golabital
Paiju bridge
Bardumal
Daily flow at Paiju
Jun 2012 - NOW
Shigar drainage basin
Discharge measurement
Shigar
Topographic survey
Daily flow at Shigar
April 2011 - NOW

Hydrologic field work

Field campaigns during 2011-2013

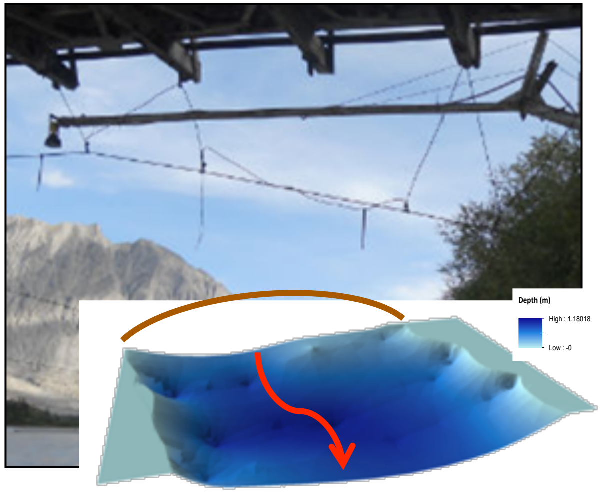
Daily flow at Shigar
April 2011-May 2013

Ablation stakes
Summer 2011-
summer 2013

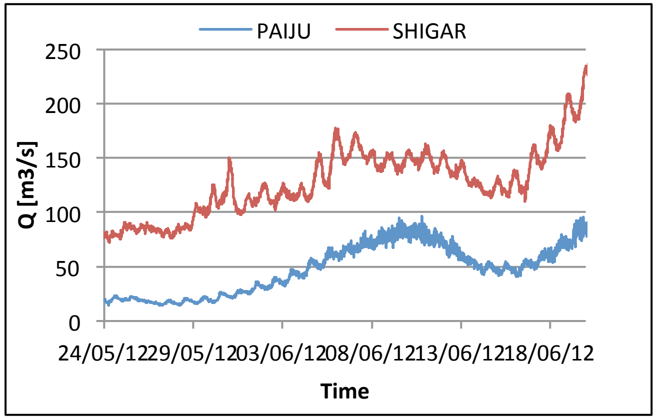
Daily flow at Paiju
Jun 2012-June
2013

The hydro stations

Shigar gauge station (ultrasonic sensor) - April 2011



Altitude	2221 m a.s.l.
Watershed area	6923 km^2
Datalogger	Campbell Scientific - CR200X
Sensor	sonic sensor Vegason 63, 4-20 mA, 24V
Power supply	solar panel 20W + battery Pb 12V 40 Ah

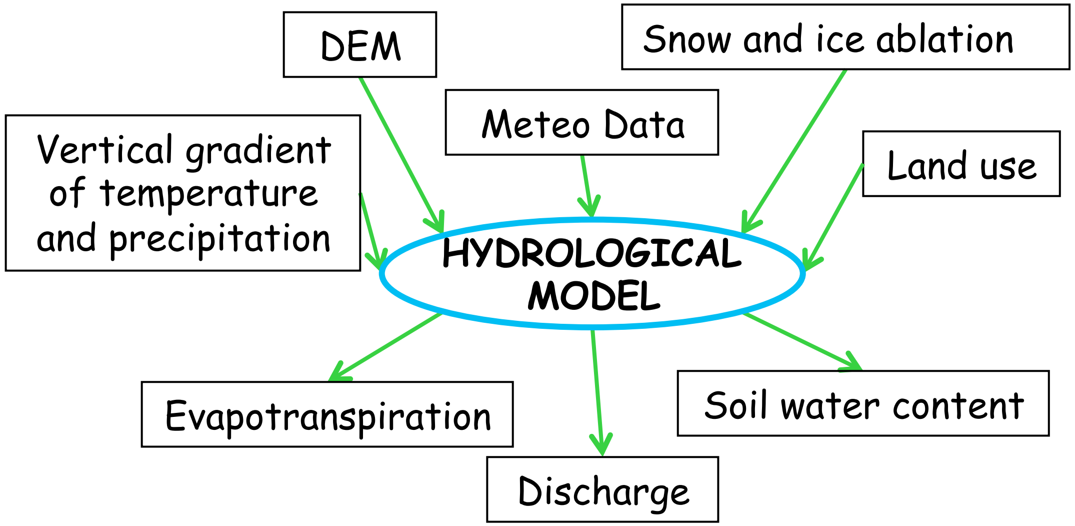


Paiju gauge station - May 2012

Altitude	3356 m a.s.l.
Watershed area	1331 km^2
Datalogger	Campbell Scientific - CR200X
Sensor	piezometric sensor STS atm.eco/n, 4-20 mA, 12V
Power supply	solar panel 20W + battery Pb 12V 16 Ah

Hydrologic Analysis

The hydrological, *Poli-Hydro* model



Simplified ice flow model

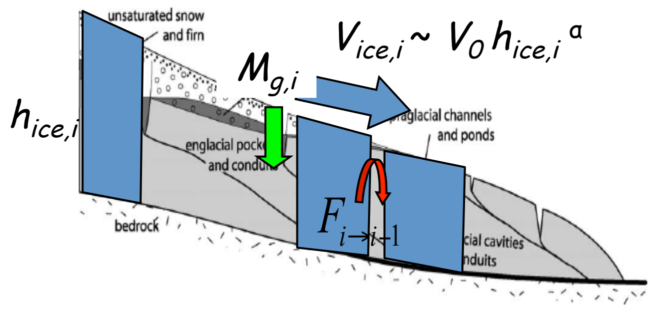


Fig. 2. The hydrological systems and locations of water storage in a temperate glacier (modified from Röthlisberger and Lang, 1987).

Daily mass balance equation

$$S^{t+\Delta t} = S^{t} + P + M_s + M_g - ET - Q_g$$

S= soil water content
P= total precipitation (rain and snow)
M_s= snow melt
M_g= ice melt
ET= evapotranspiration
Q_g= groundwater flow

Daily storage-outflow equation

$$Q_s = S^{t+\Delta t} - S_{Max} \qquad se \;\; S^{t+\Delta t} > S_{Max}$$

$$Q_s = 0 \qquad se \;\; S^{t+\Delta t} \le S_{Max}$$

Runoff production:
Q_s= superficial flow
S_{max}= max soil water content

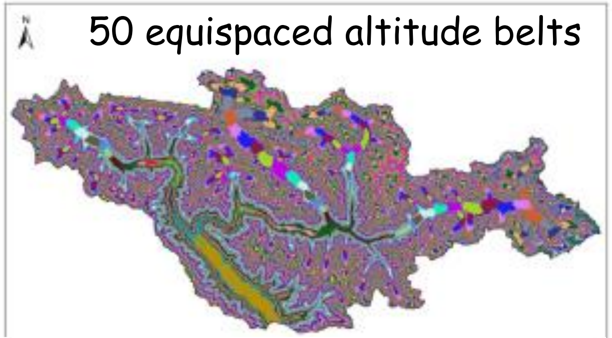
Ice melt, based on positive degree day factor

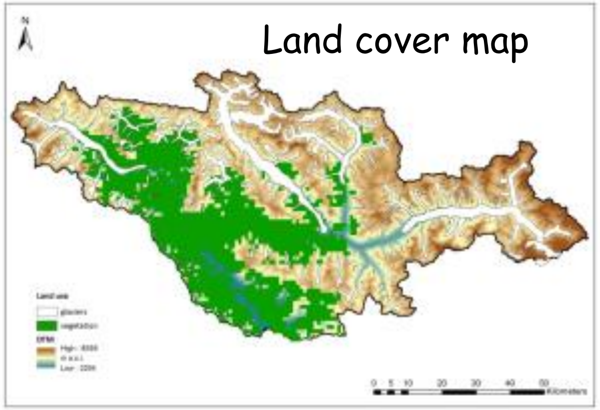
$$M_i = PDDF_i \left(T - T_{th}\right) \;\; if \; T \ge T_{th}$$

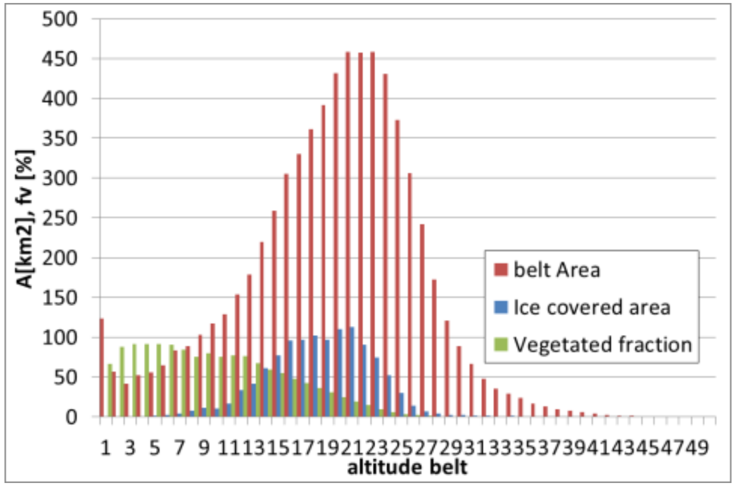
$$M_i = 0 \qquad if \; T < T_{th}$$

Ice thickness upon the Baltoro glacier was estimated in Summer 2013, using a low frequency radar antenna (50 MHz) installed on a portable instrument (SIR 3000), to be used in our simple ice flow model.

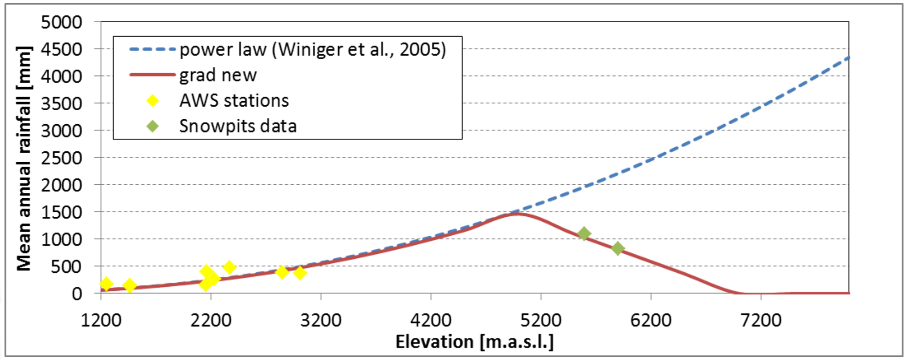
Hydrological model Input







Uncertain precipitation

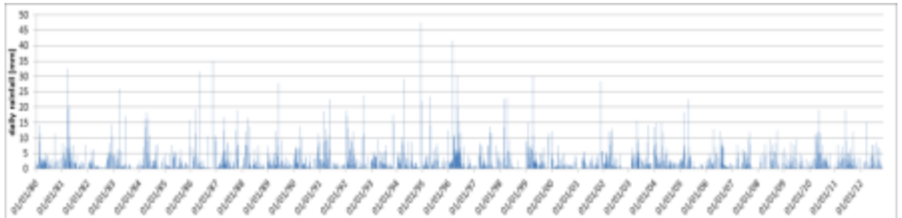


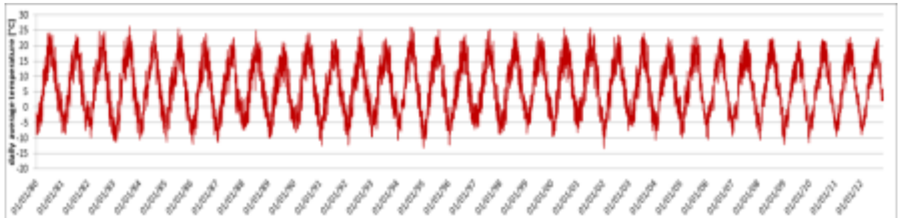
Available meteorological data

station	available data	temporal resolution
Askole	2005-2012	daily
Astore	1980-2009	monthly

Monthly mean flow data available at Shigar from 1985 to 1997

Statistical downscale on monthly Astore data based on daily Askole data

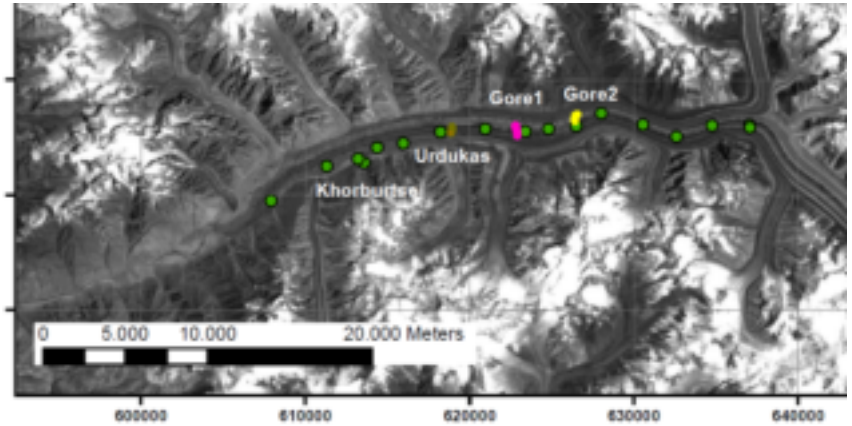


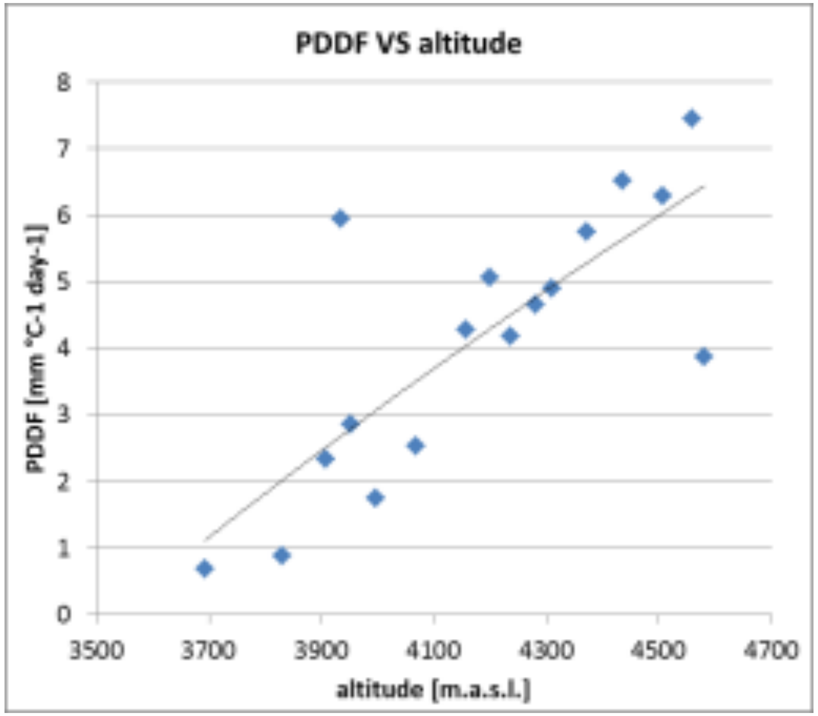


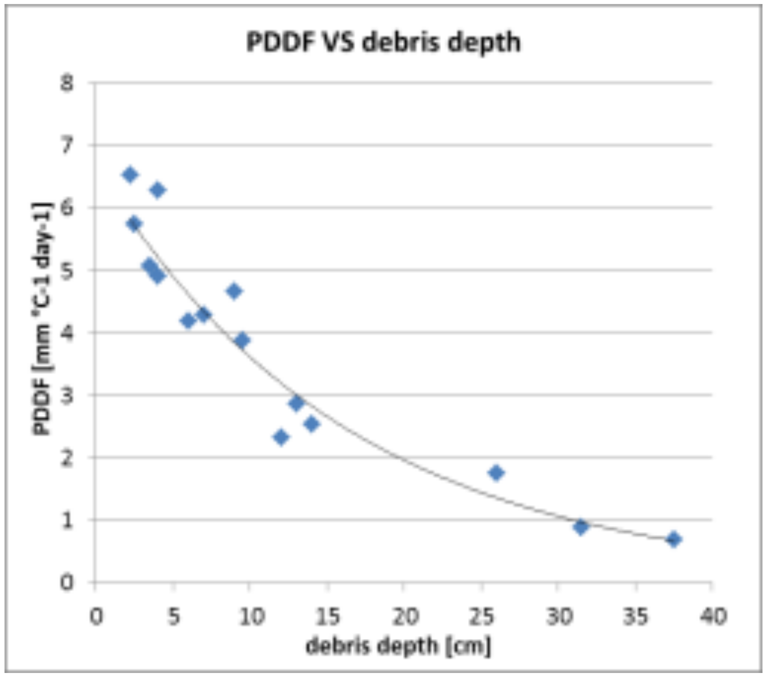
Hydrological model
Ice Positive Degree-Day Factor Estimation

Ice ablation data collected in summer 2011 by a UNIMI_POLIMI field campaign:

- Debris depth at 17 points
- Ablation data at 17 ablation stakes



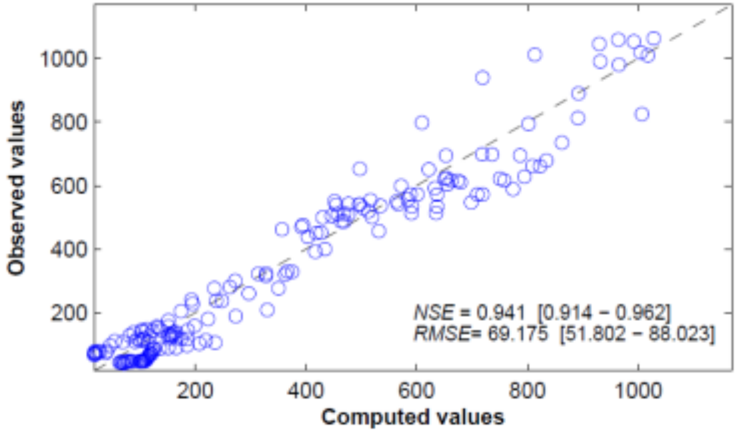


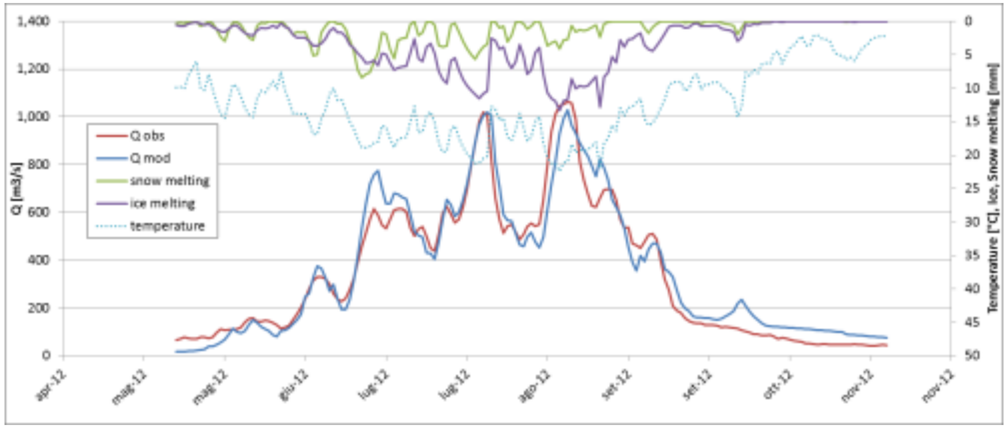


Multiple regression used to stimate PDDF at each altitude belt

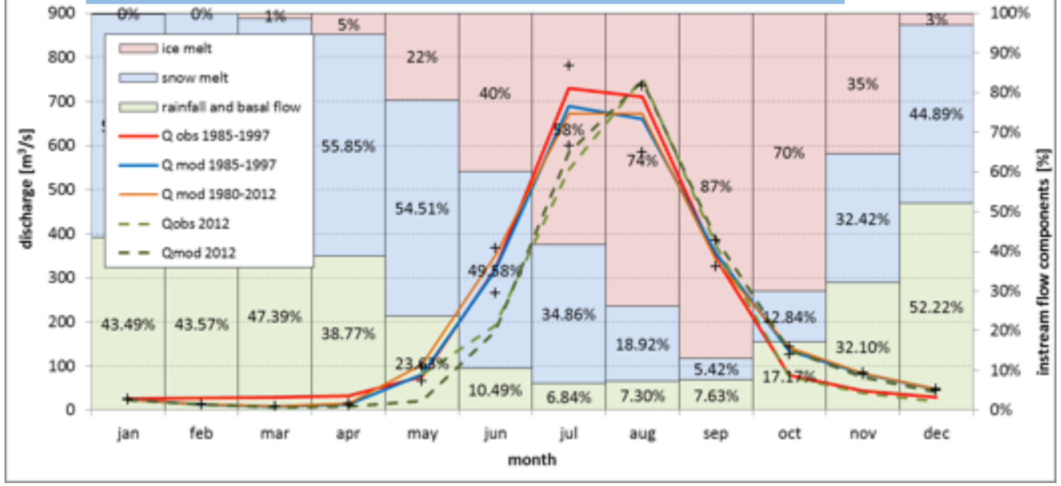
Hydrological model

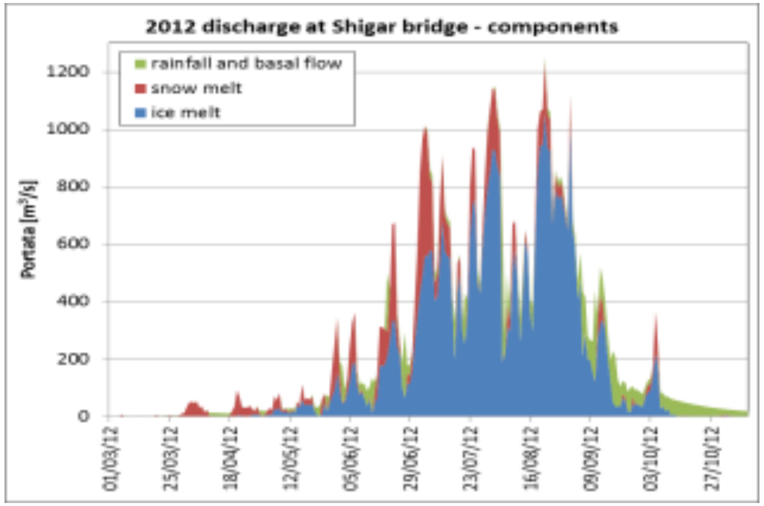
Calibration 1985-1997 monthly data at Shigar





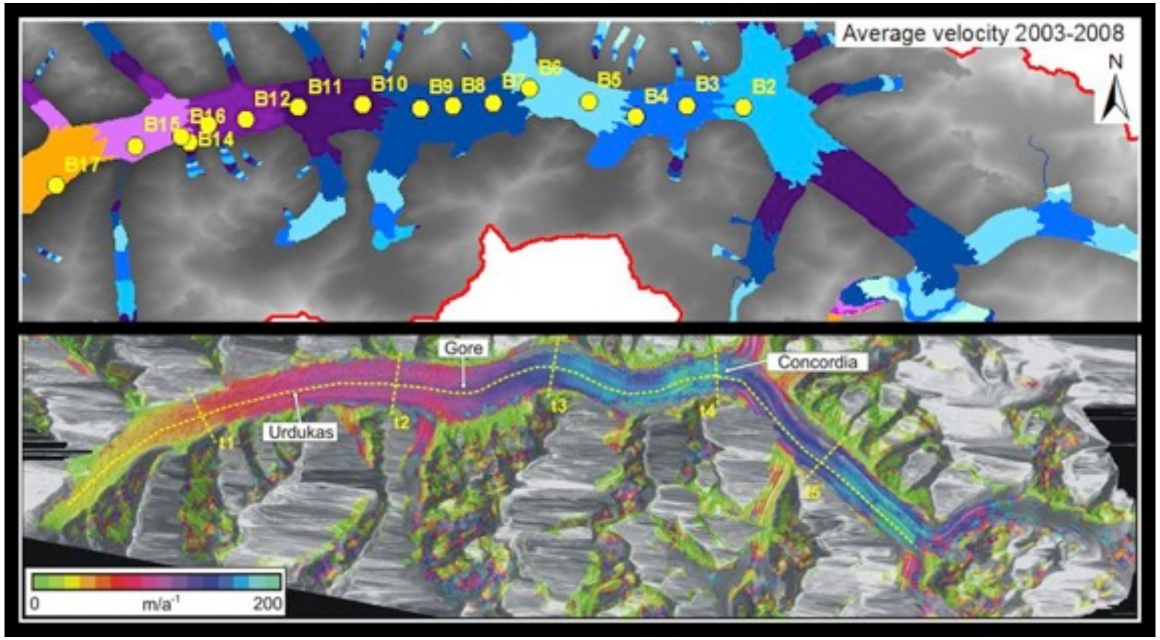
In summer, melt ca. 70% of Q





	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	average
observed 1985-1997	26.07	27.76	28.55	31.81	76.47	319.42	729.21	710.09	343.53	78.71	44.13	29.05	203.73
model 1985-1997	24.05	13.43	8.72	12.78	81.27	316.22	690.03	659.95	355.54	134.27	82.60	46.61	202.12
model 1980-2012	24.07	13.23	8.49	14.60	102.16	350.68	672.78	672.71	341.39	142.38	83.61	47.24	206.11
observed Shigar 2012	-	-	-	-	80.98	190.63	544.93	753.20	373.54	76.36	45.00	-	294.95
model Shigar 2012	22.13	12.16	7.24	7.57	21.21	177.61	583.76	746.11	387.16	136.55	82.80	-	305.03

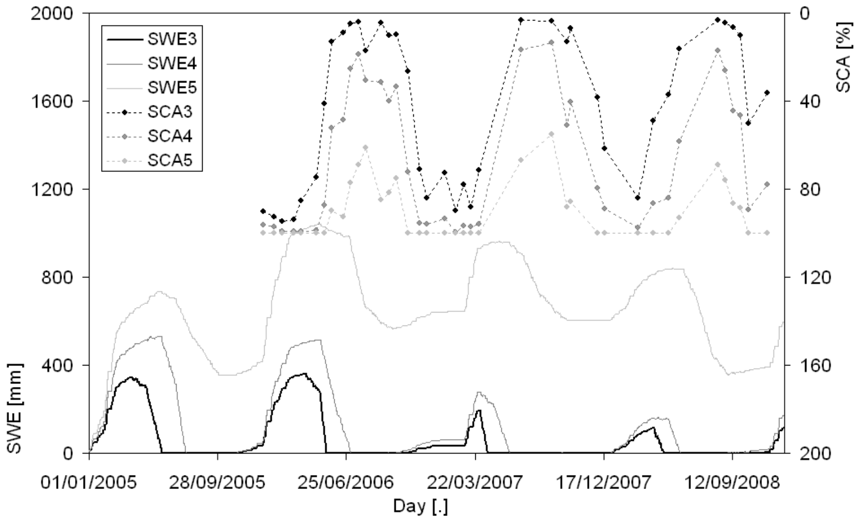
Ice flow- validation



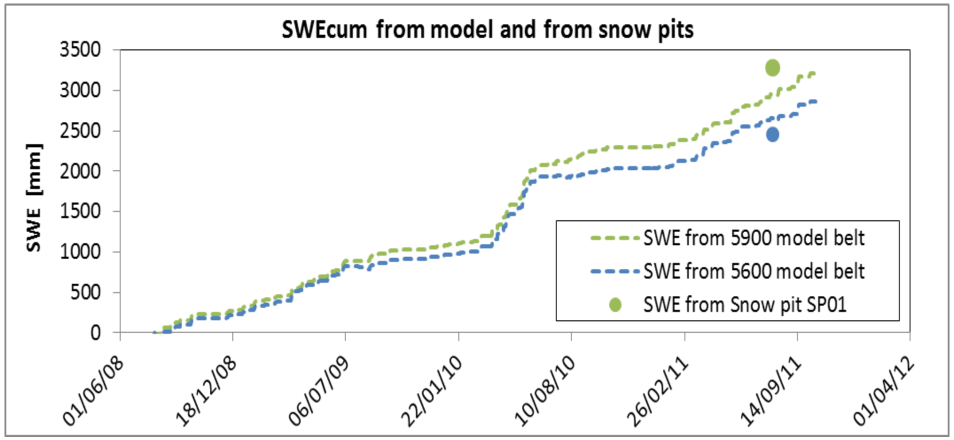
Our model

Quincey, D.J., Glasser N.F., Braun, M., Bishop, M.P., Hewitt, K. and Luckman, A. (2011). Karakoram glacier surge dynamics, Geophysical Research Letters, 38, doi: 10.1029/2011GL049004.

Snow cover-validation



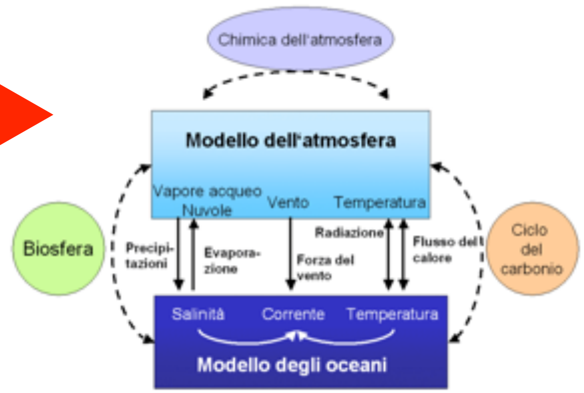
Snow pits at ca. 6000 m asl



The future (of) climate&hydrology, can we figure that out ?

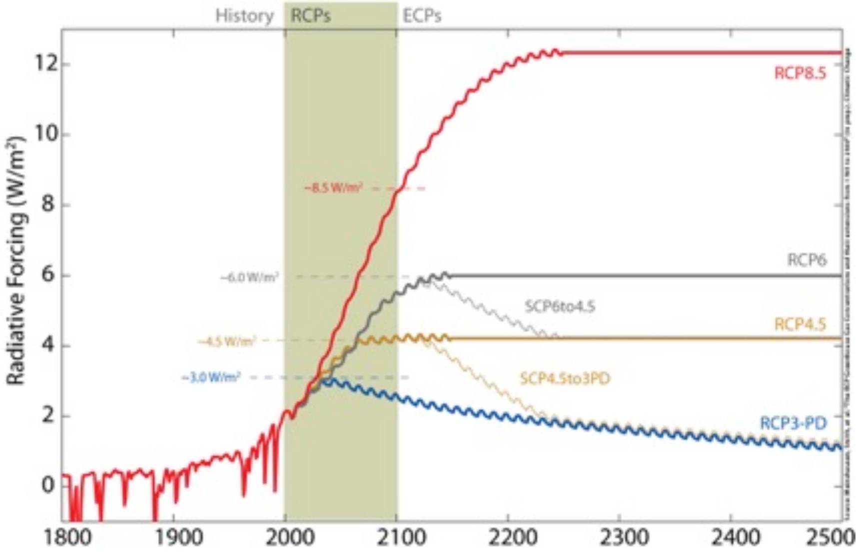
To investigate change of the hydrological, one can use **the projections of climate models (AKA GCMs).** These models do not provide a deterministic forecast of the future climate, but instead, a possibily representative, statistically likely set of climate conditions that may occur under specific hypothesis concerning greenhouse gasses concentration (and/or radiation budget).

A climate model is a simplified version of the earth's system elaborated by a computer that represents reasonably the physical and chemical interactions occurring therein. Main components of the earth's system are simulated using parameterization of experiments carried out for the purpose

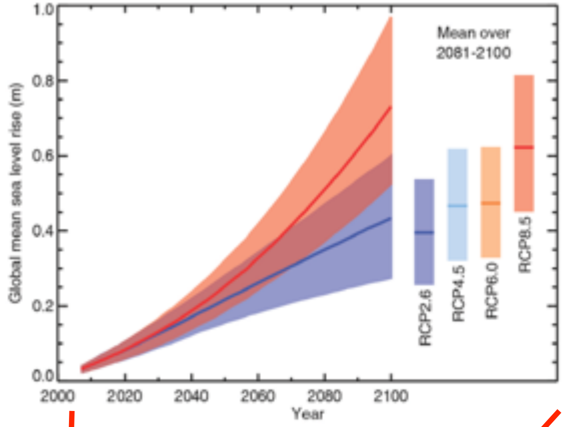


Climate projections: the RCPs (another way to represent GHGs, and CO_2 equivalent)

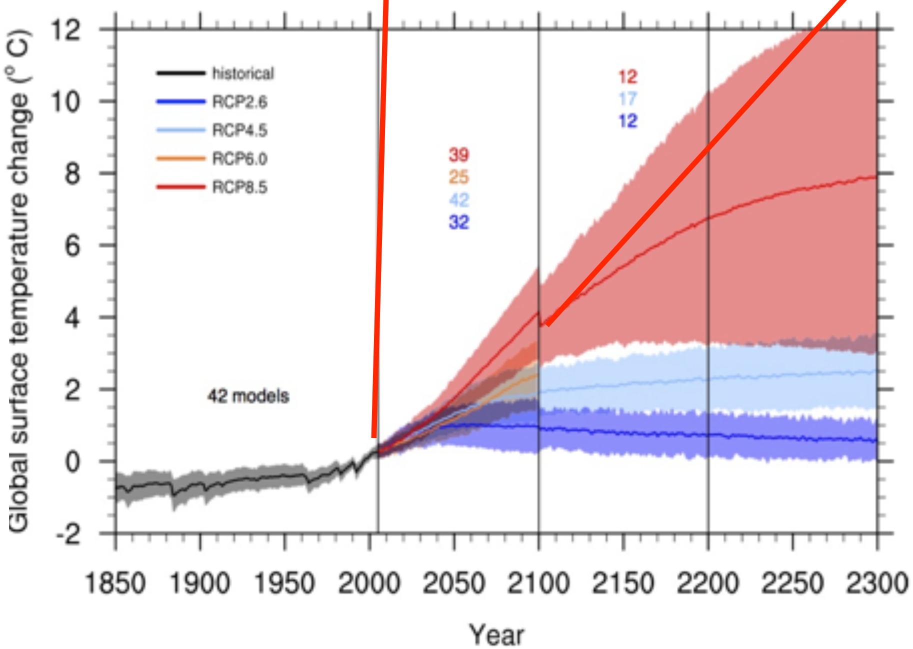
Radiative forcings



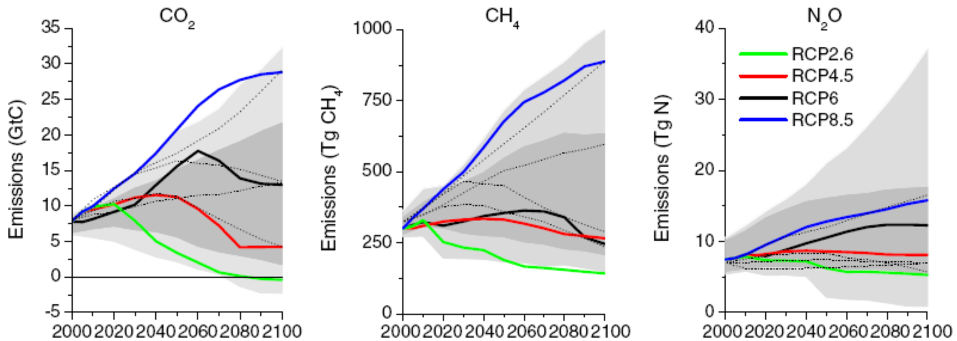
Global sea level rise



Global temperatures



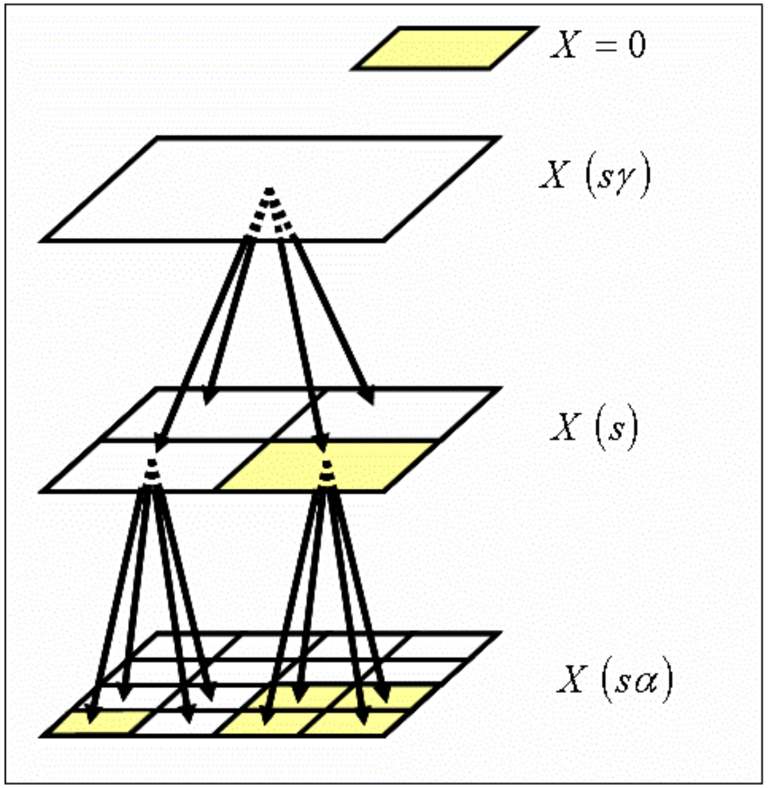
GHGs



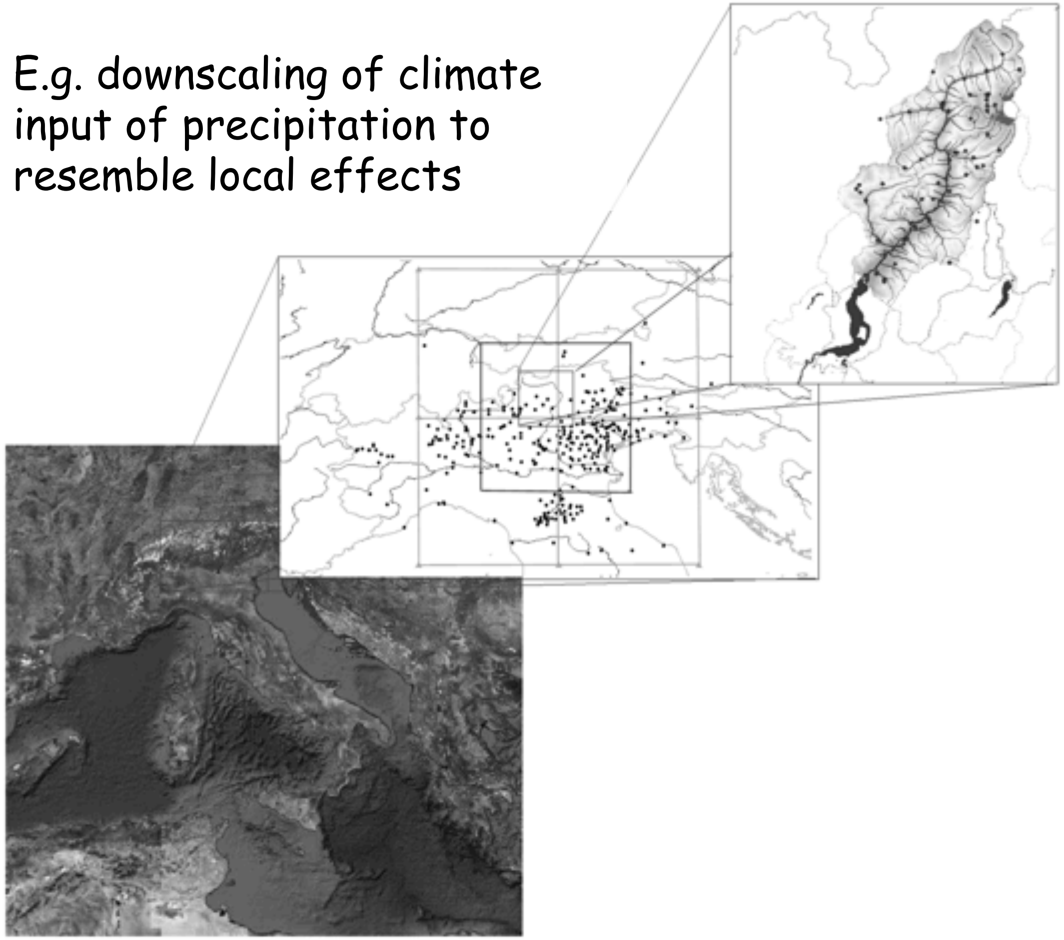
Climate models: the issue of local representativity

Climate models however generally work at a coarse resolution in space (ca. 50-100 km grid), and indeed provide climatic conjectures that are acceptable on average at large (global) scales, but generally do not interpret local variability, e.g. local conditions, topography, etc..

Therefore, local tailoring is required, i.e. normally referred to as (statistical, dynamic, deterministic) ***downscaling,*** **especially for precipitation**



E.g. downscaling of climate input of precipitation to resemble local effects



The future (of) hydrology, can we figure that out ?

Hydrological projections
GCMs for scenario simulations

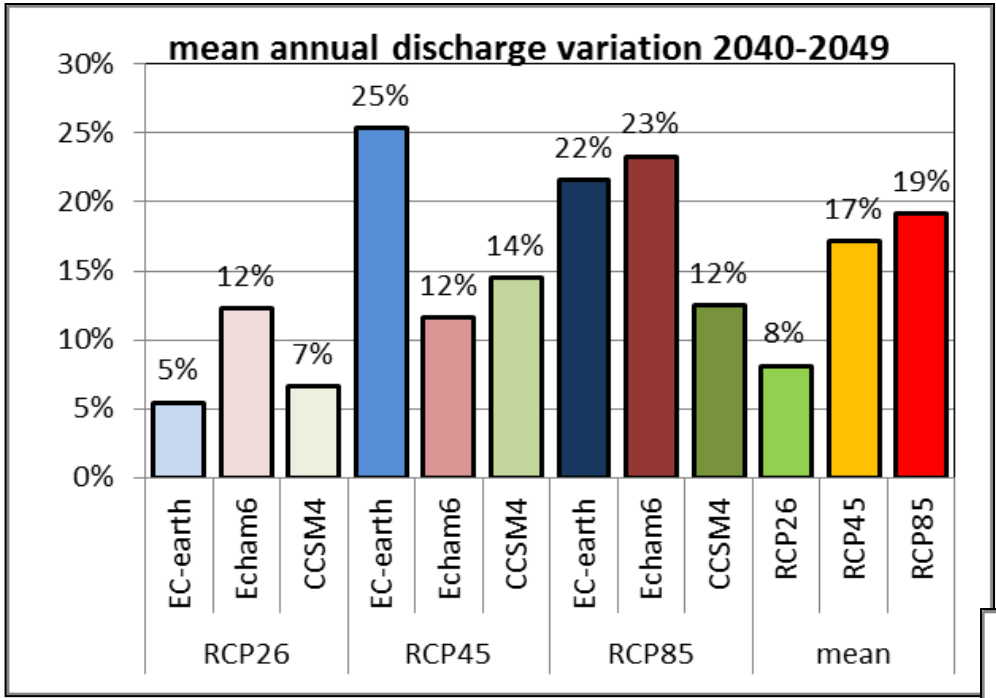
PAPRIKA used **downscaled inputs** from three different GCMs to project forward hydrology of the Shigar river over the investigated time horizon (until 2099)

Model	Research Centre	Nation	Grid size [°]	n° layers [.]	n° cells [.]
EC-EARTH	Europe-wide consortium	E.U.	1.125° x 1.125°	62	320x160
ECHAM6	Max Planck Institute for Meteorology	GER	1.875° x1.875°	47	192x96
CCSM4	National Center for Atmospheric Research	U.S.A.	1.25° x 1.25°	26	288x144

Projected Mean Annual Discharge

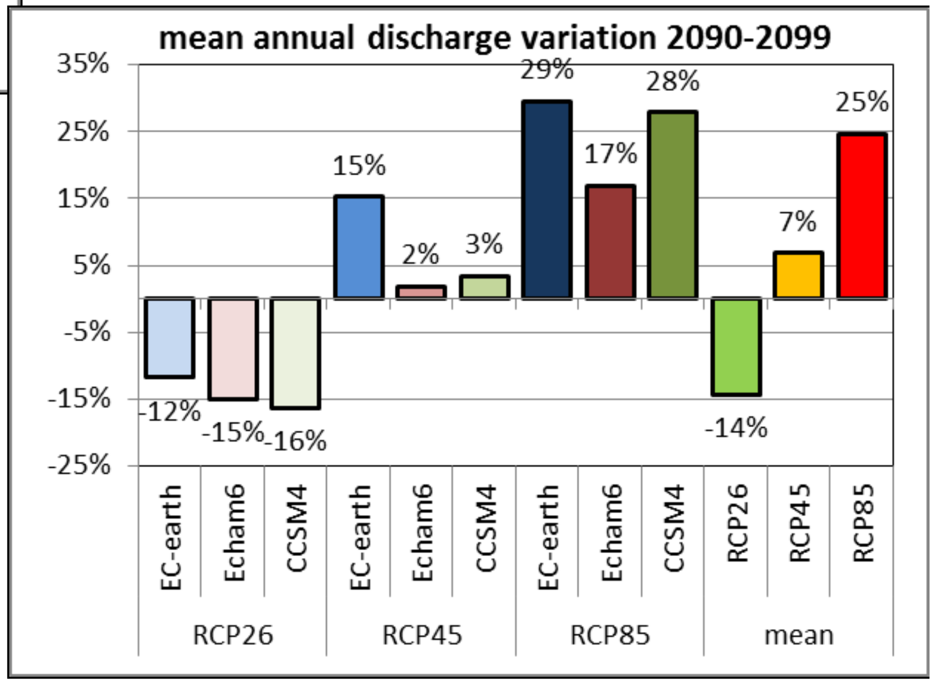
Hydrological projections

Hydrologic scenarios



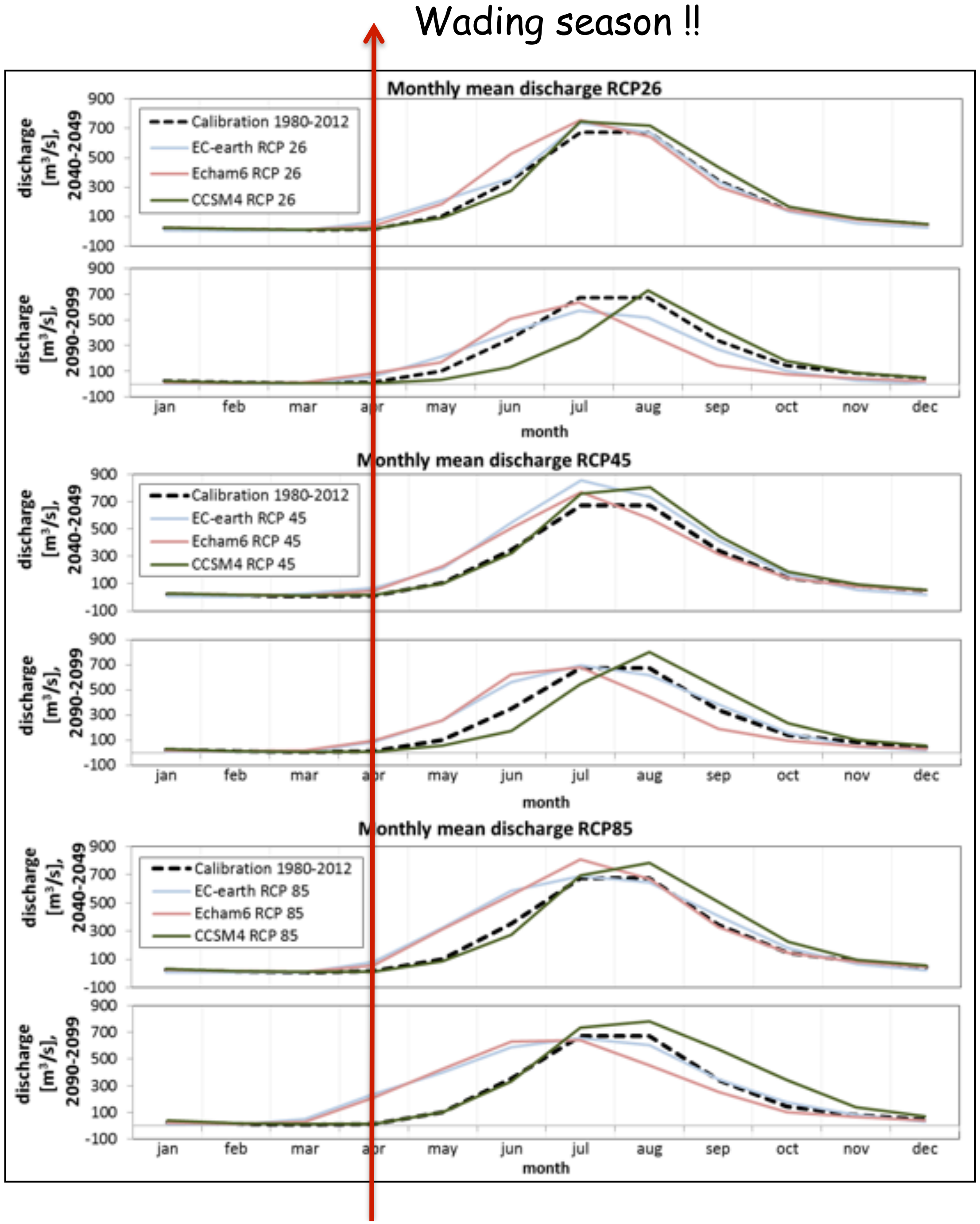
Half century: increase

End of century: potential decrease



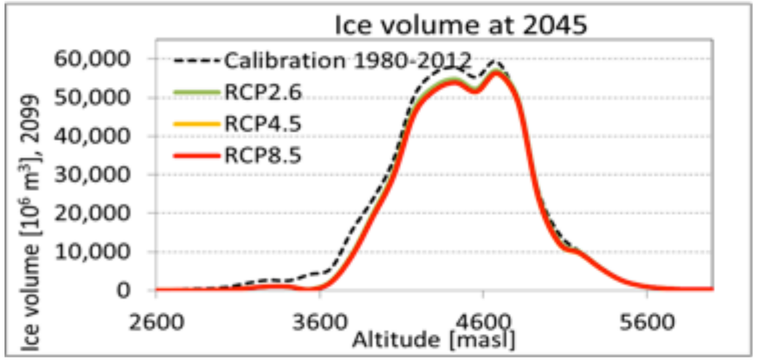
Hydrological projections

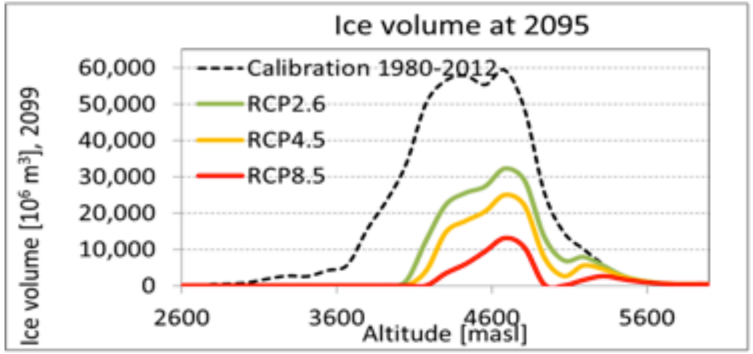
Hydrologic cycle (monthly)



Streamflow will increase during the warm season, as sustained by ice melt, especially during July and August, but with a potential shift of high flows towards Spring months

Hydrological projections: available ice volume as per altitude bins





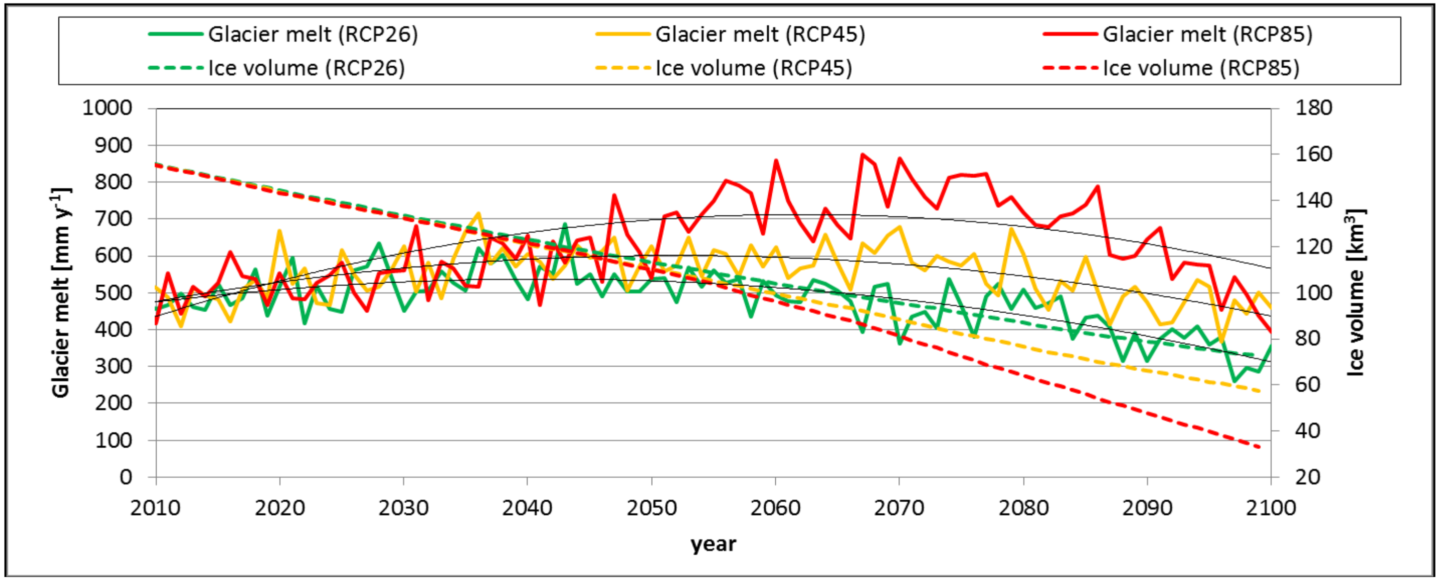
RCP 2.6		
% ice volume lost	2040-49	2090-99
EC-earth	-8.4%	-63.9%
Echam6	-11.2%	-62.0%
CCSM4	-7.2%	-55.4%

RCP 4.5		
% ice volume lost	2040-49	2090-99
EC-earth	-11.3%	-76.6%
Echam6	-10.5%	-71.8%
CCSM4	-7.2%	-70.1%

RCP 8.5		
% ice volume lost	2040-49	2090-99
EC-earth	-11.2%	-91.0%
Echam6	-14.2%	-90.7%
CCSM4	-7.4%	-86.0%

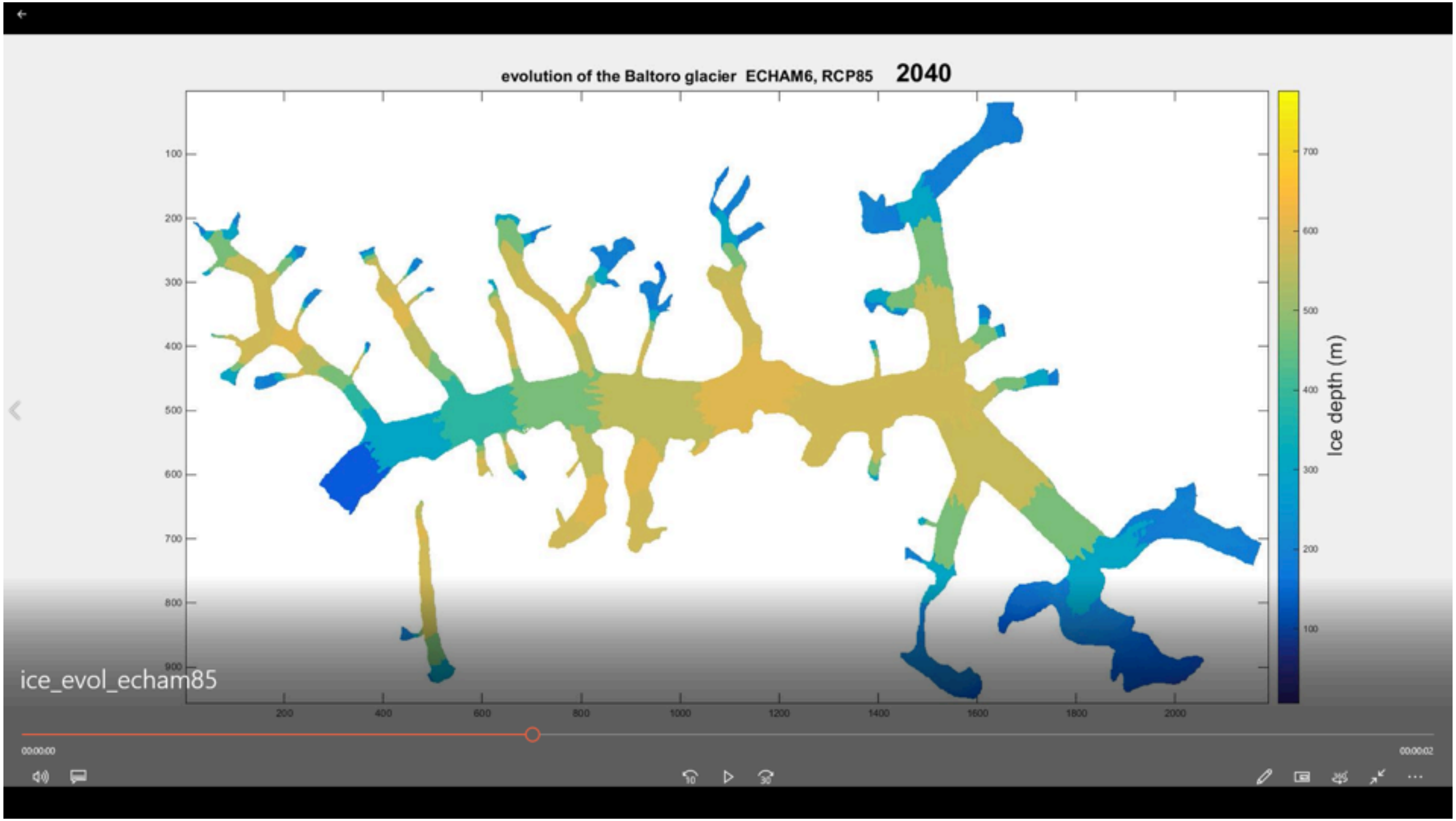
Accelerated ice melting will lead **to rapidly decreasing ice thickness**, with potential thinning, especially towards the end of the century.

Down wasting of ice cover may have several implication, hydrologically, ecologically, climatically, and touristically



The future Baltoro glacier, a movie

ECHAM6, "worst case" RCP8.5 scenario

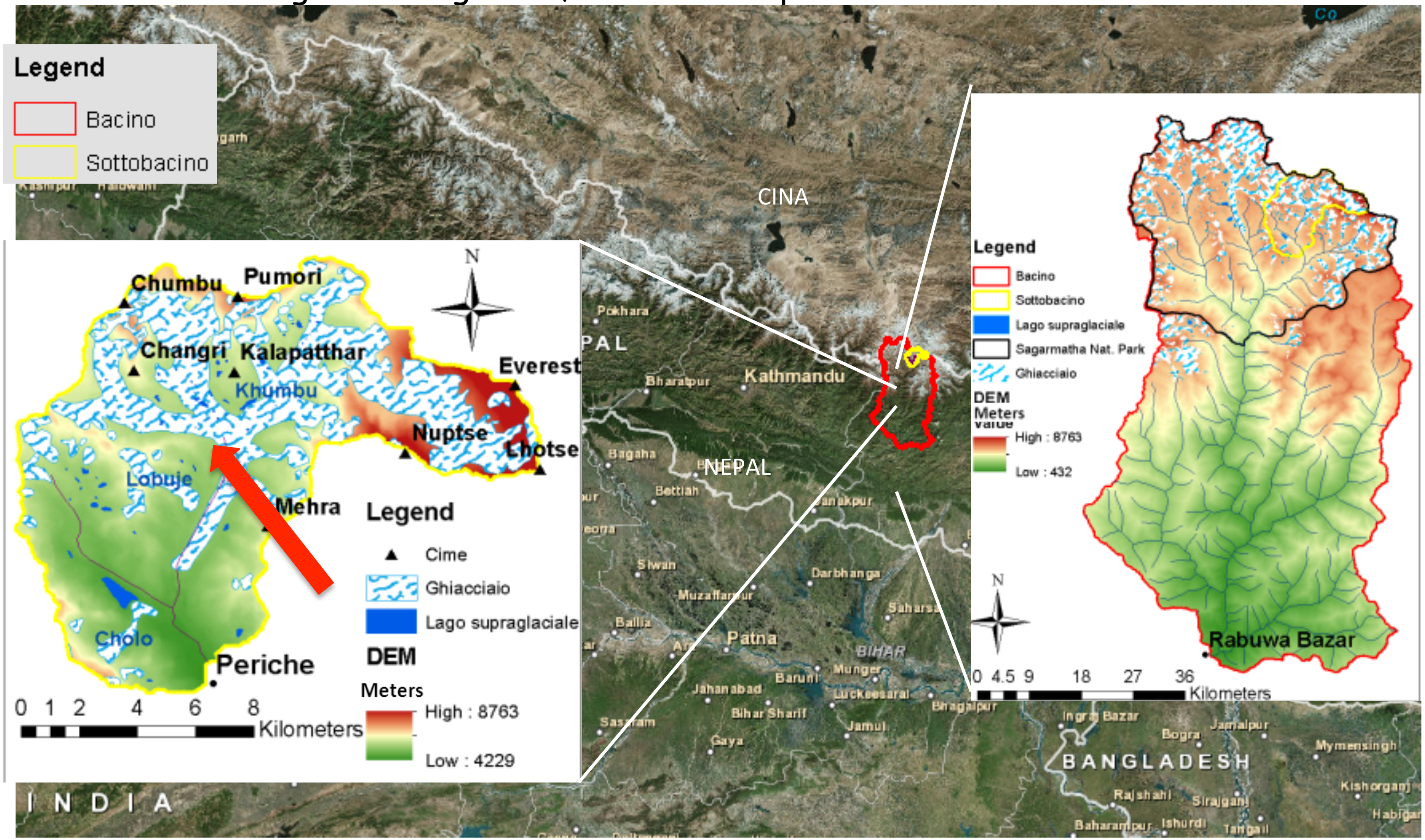


The animation displays ice thickness in each altitude belt on the Baltoro glacier during 2020-2100. Worst case scenario, Model ECHAM6, RCP8.5

Common traits arising

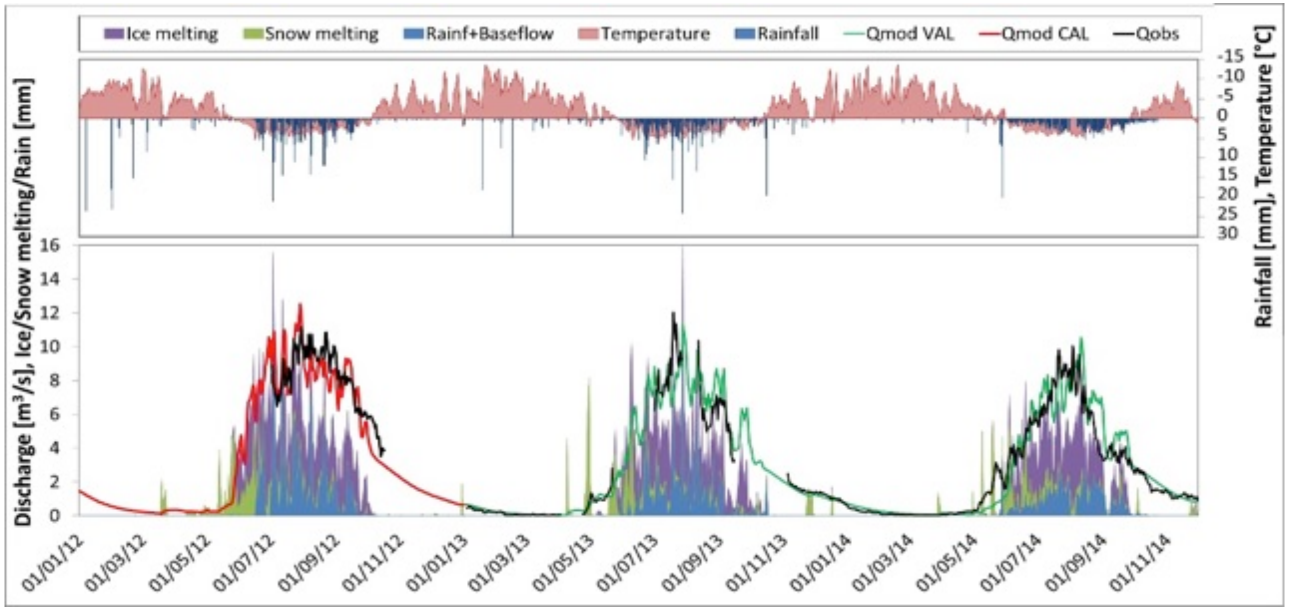
2012-2015: Monitoring and modeling hydrology of the Khumbu glacier and Dudh Koshi basin, Nepal

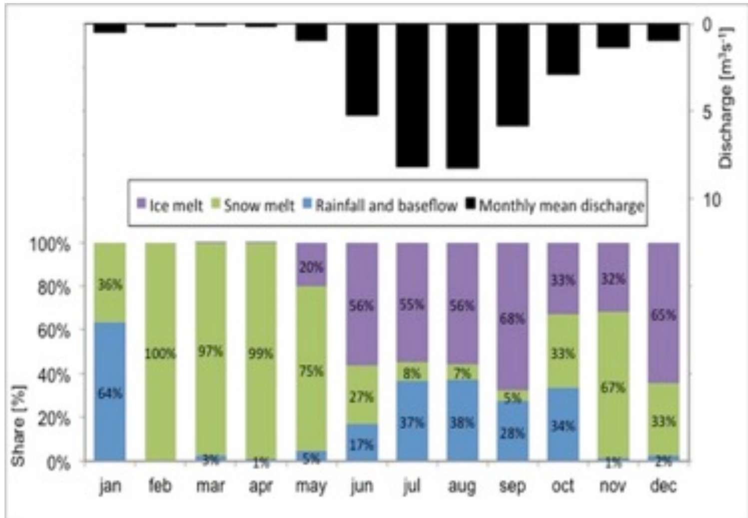
Dudh Kosi river including Khumbu glacier, and Everest peak



Hydrological model

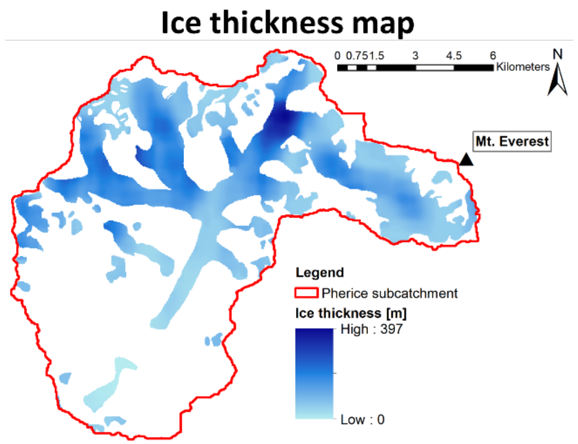
Calibration/validation (2012-2014)-
at Pherice (4200 masl)





Flow share

Ice thickness map
(CELL BASED !!!)

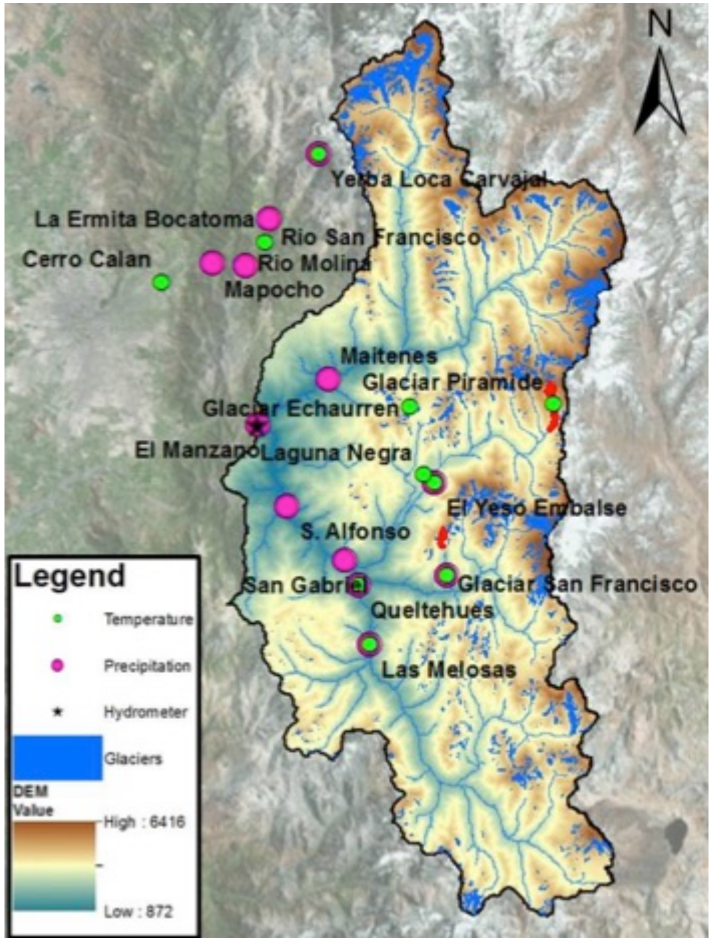


Common traits arising

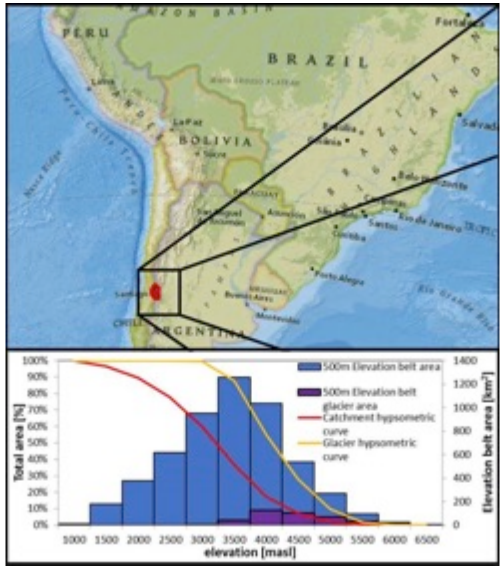
The (central) Andes

Chile: large monitoring, high altitude network

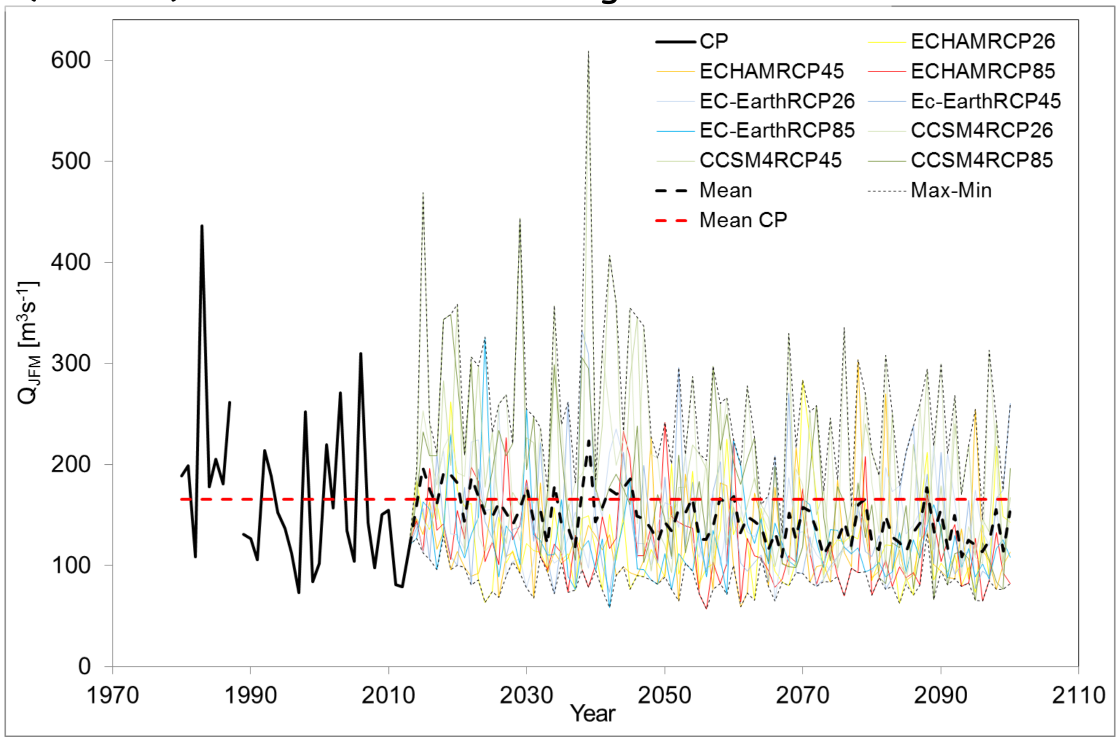
Case study: Maipo river (ca. 4900 km^2), Santiago



2012. Programa plan de acción para la conservación de glaciares ante el cambio climático, DGA Cile

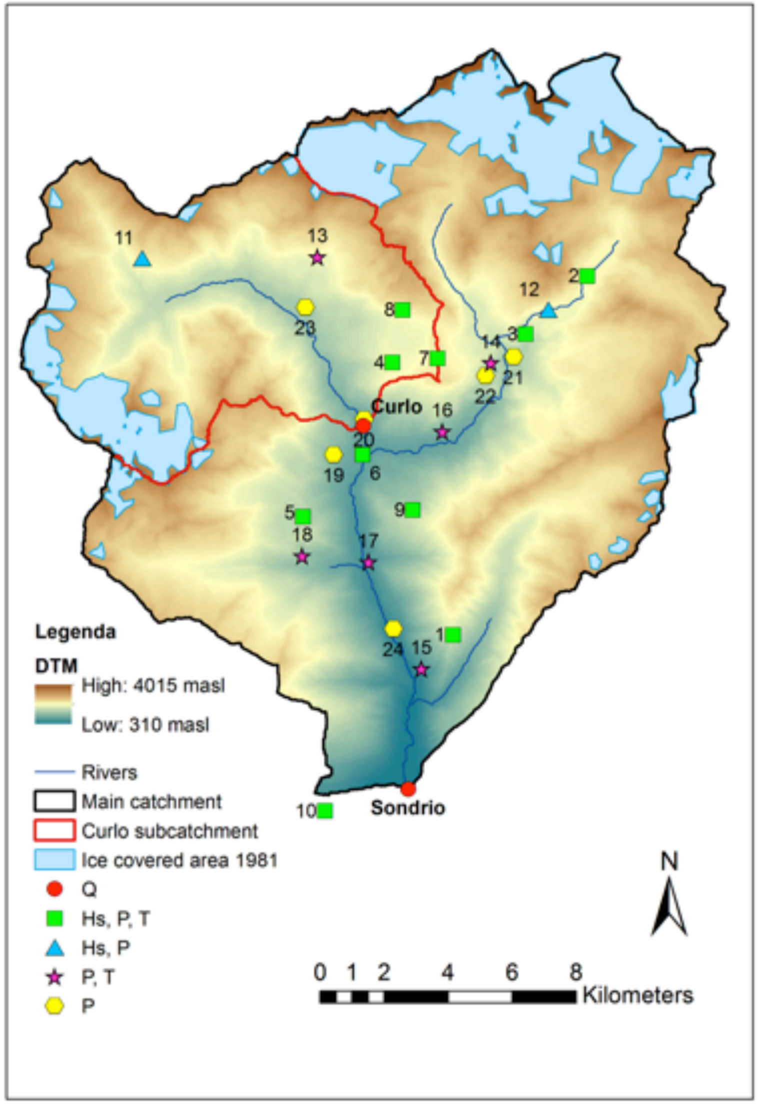


(Austral) summer flow decreasing until 2100



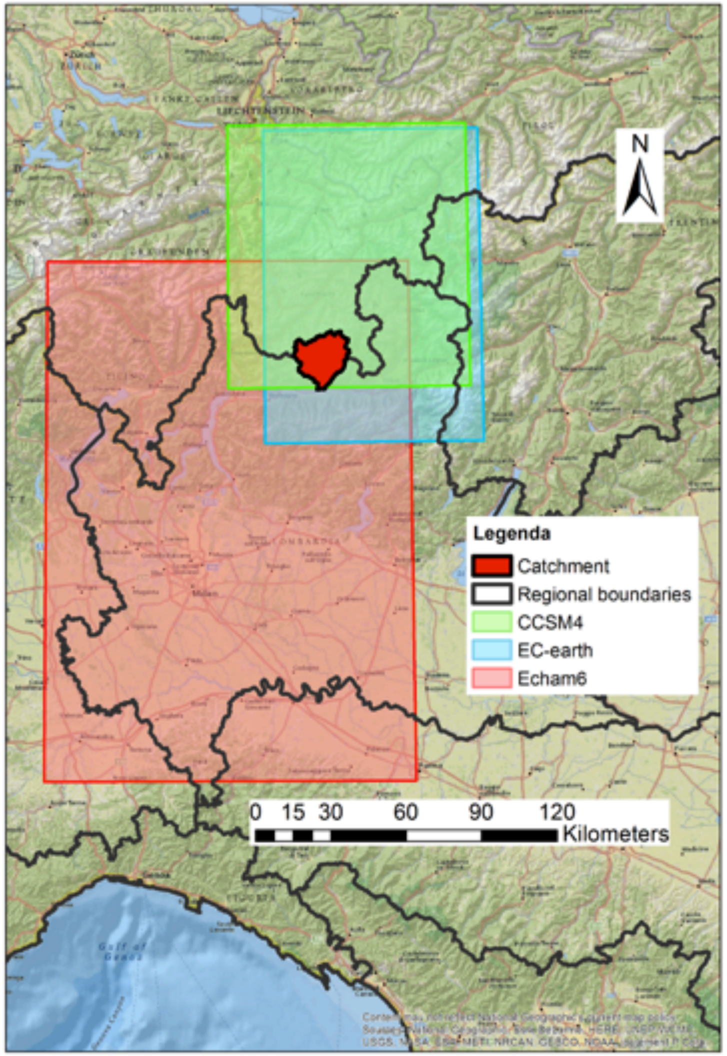
An Italian case study

Bernina-Mallero case study



Heavily regulated

Little (!!!) hydrological information !



Glaciers contribution

Ice mass budget deduced from remote sensing

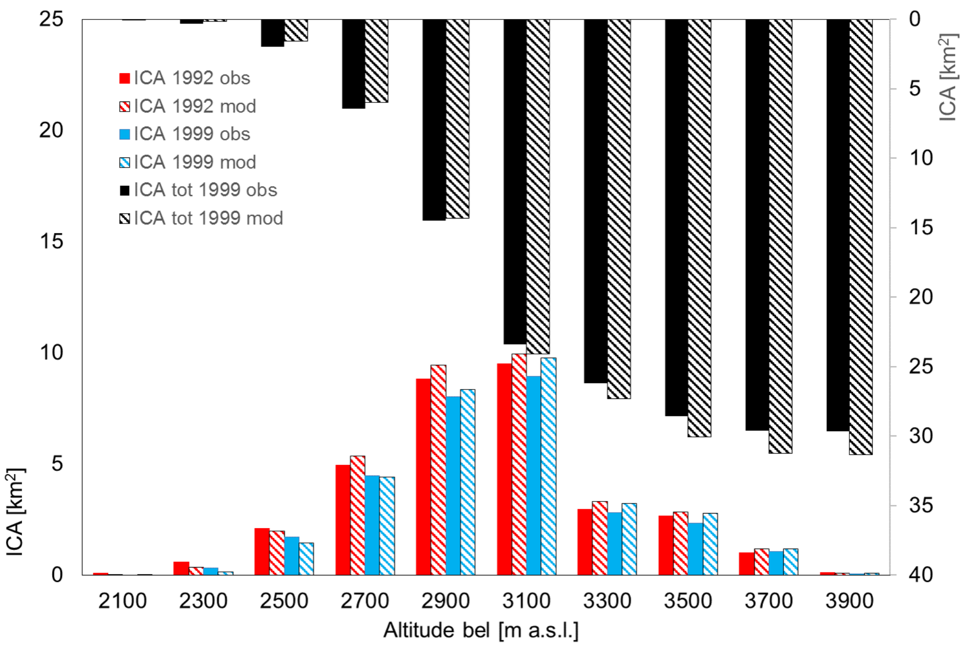
DEM 2007- DEM 1981 = IWE_m

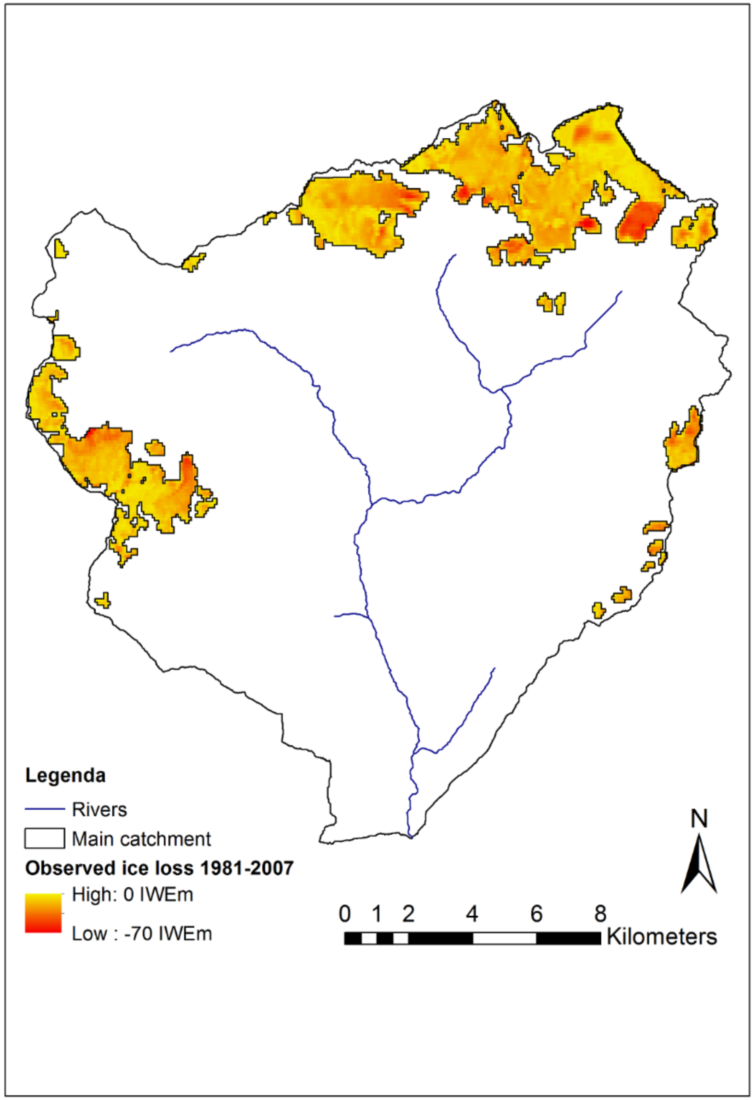
Altitude difference can be used to assess ice melt in water equivalent.
Ice/snow melt can be modelled using mixed approaches, using temperature *T*, radiation global *G*

$$M_{ci,s} = \left(TMF_{ci,s}\left(T - T_{th}\right) + RMF_{ci,s}\left(1 - \alpha_{ci,s}\right)G\right) \; if \; T \geq T_{th}$$

$$M_{ci,s} = 0 \qquad if \; T < T_{th}$$

Difference of ice covered area ICA can be used to validate modeling

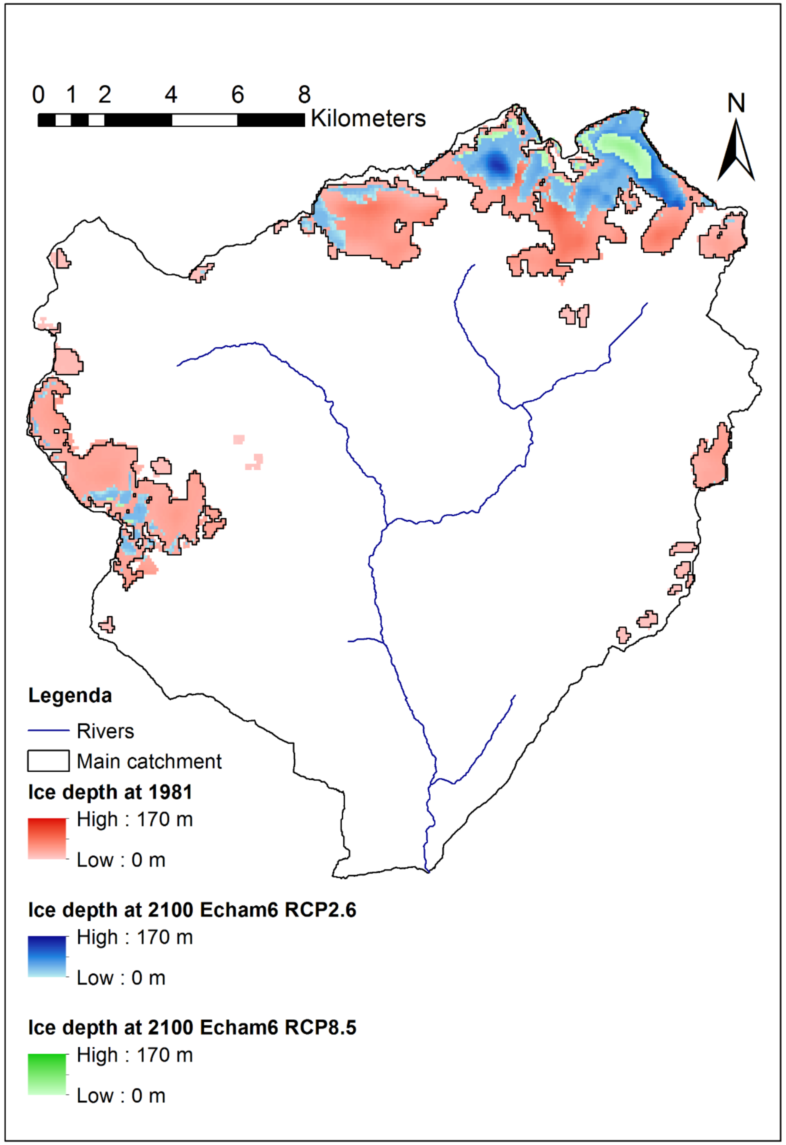


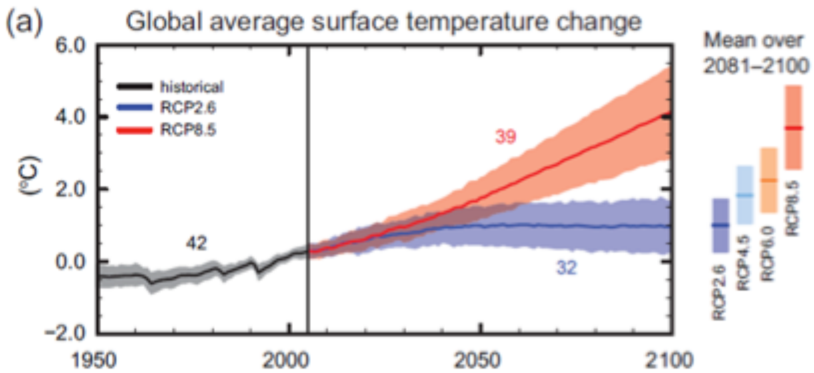


Ice covered area at each altitude 1992-1999

A glance into the (likely) future

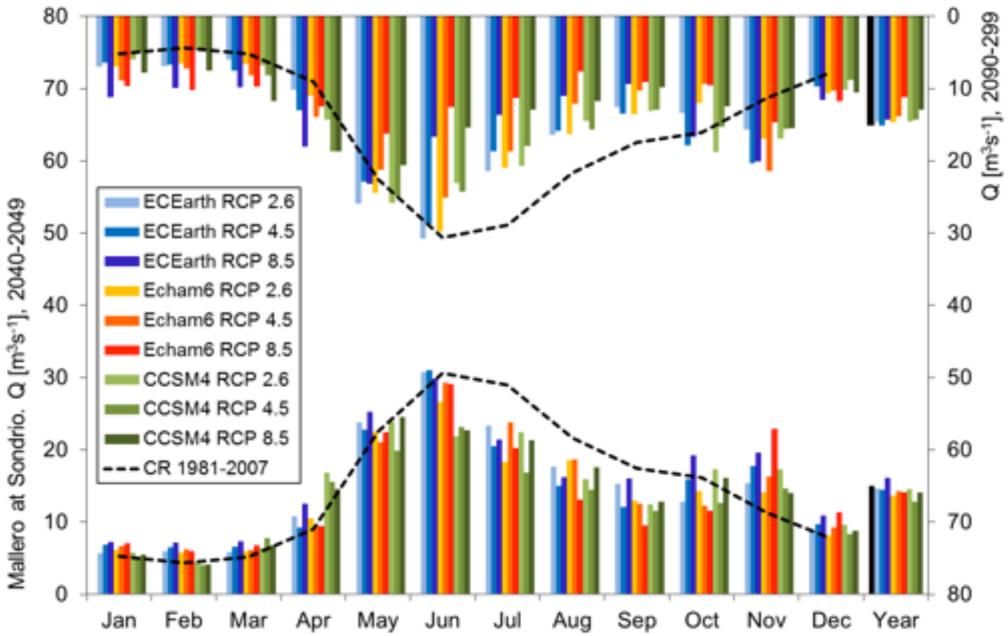
Using IPCC projected climate scenarios we can then project forward the fate of the cryosphere, and of water resources





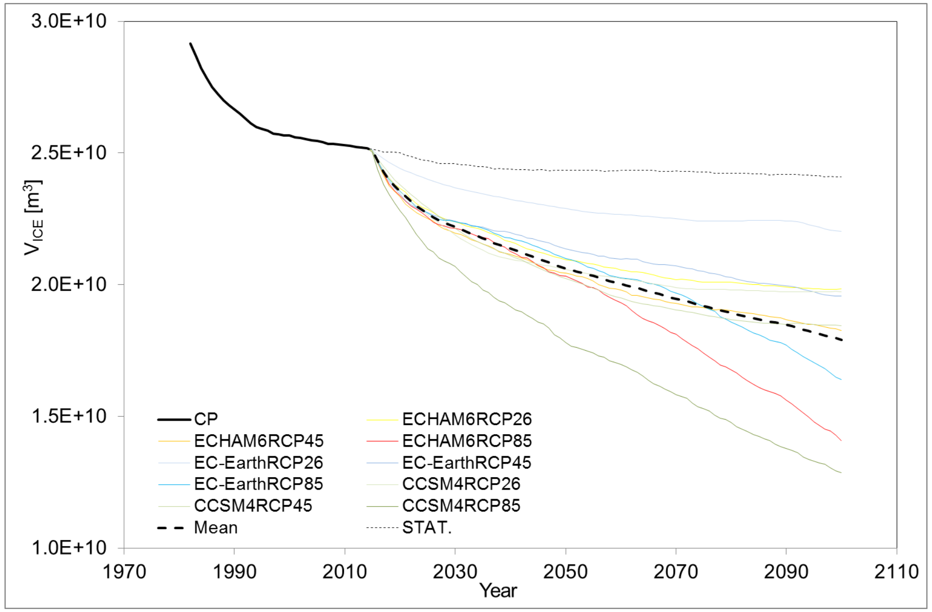
We represent here (glacier-wise) best/worst case,projected at 2100

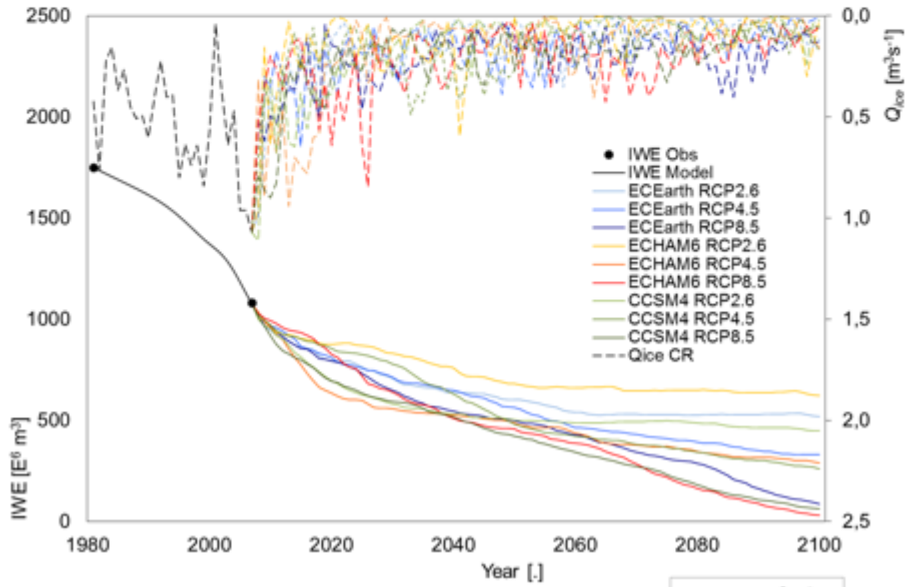
Stream flows at 2050, 2100



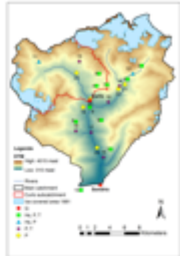
Common traits arising

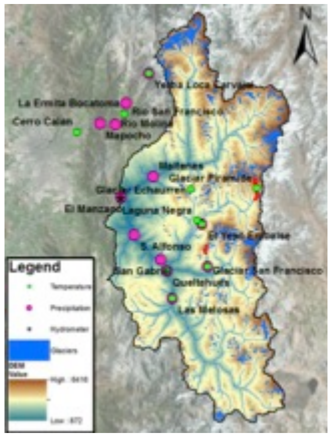
A comparison of (projected) glaciers' evolution in our case study area

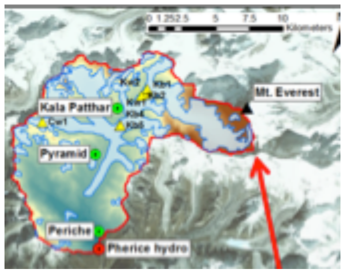


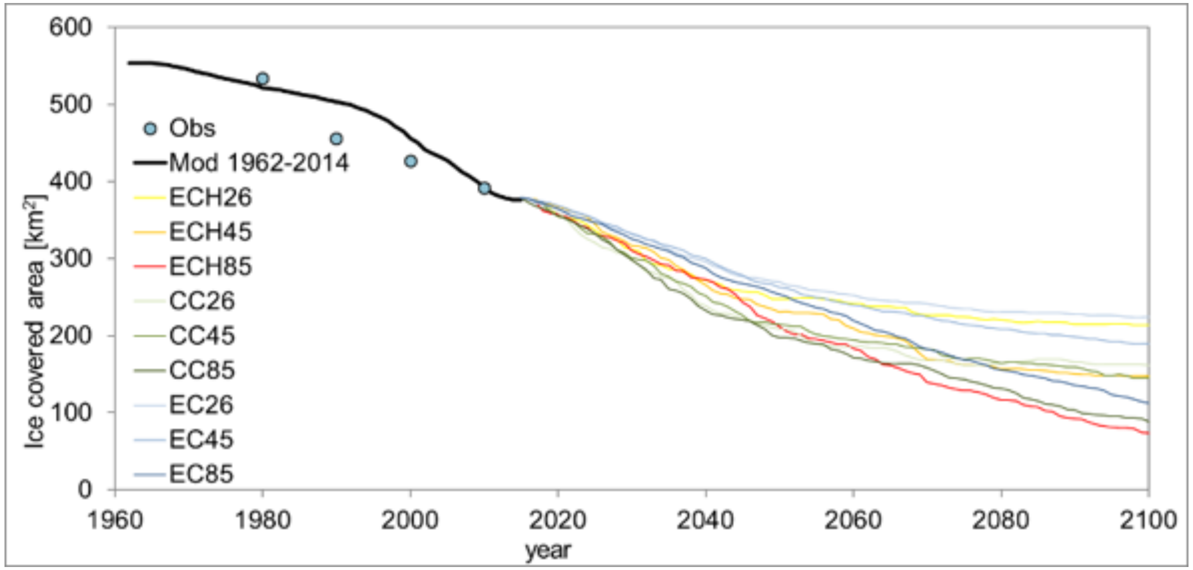


Different stages of the same process !!!









The Karakoram anomaly ???

Article

Glacier area stability in the Central Karakoram National Park (Pakistan) in 2001–2010: The "Karakoram Anomaly" in the spotlight

Progress in Physical Geography
1–32
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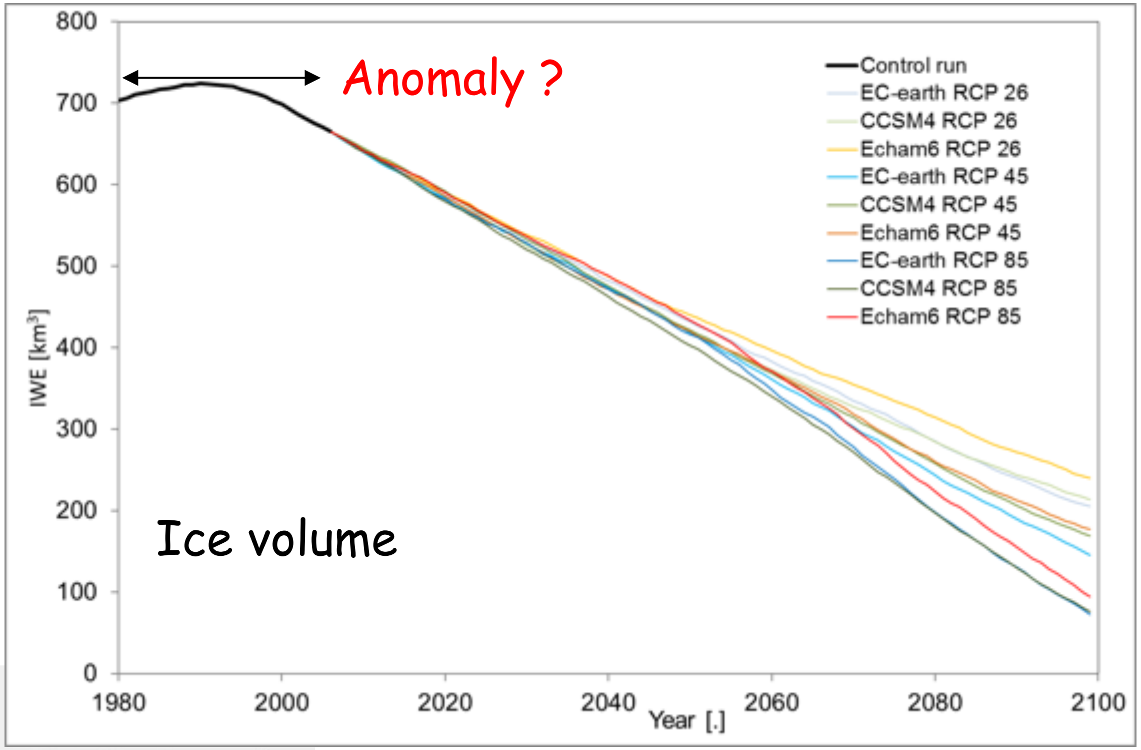
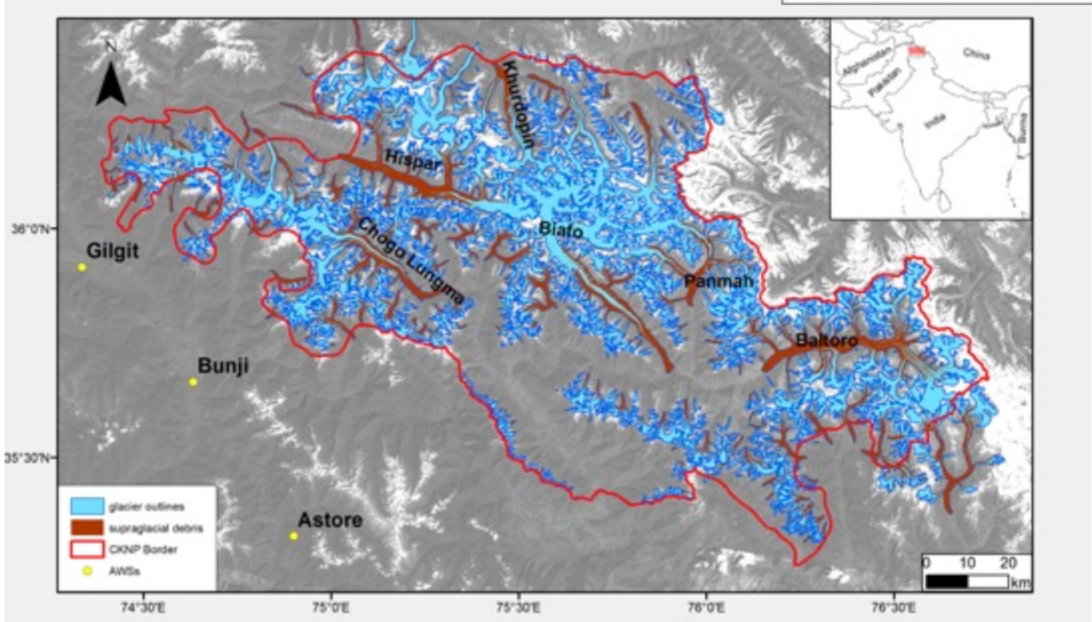




This all pleonastic ? Expected fallouts

1) Mountain water distribution/chemistry in the mountain

2) Floods/droughts - open..

3) Hydropower production

4) River habitat, temperatures

5) Rain fed mountain agriculture/pasture - MOUPA Pr.

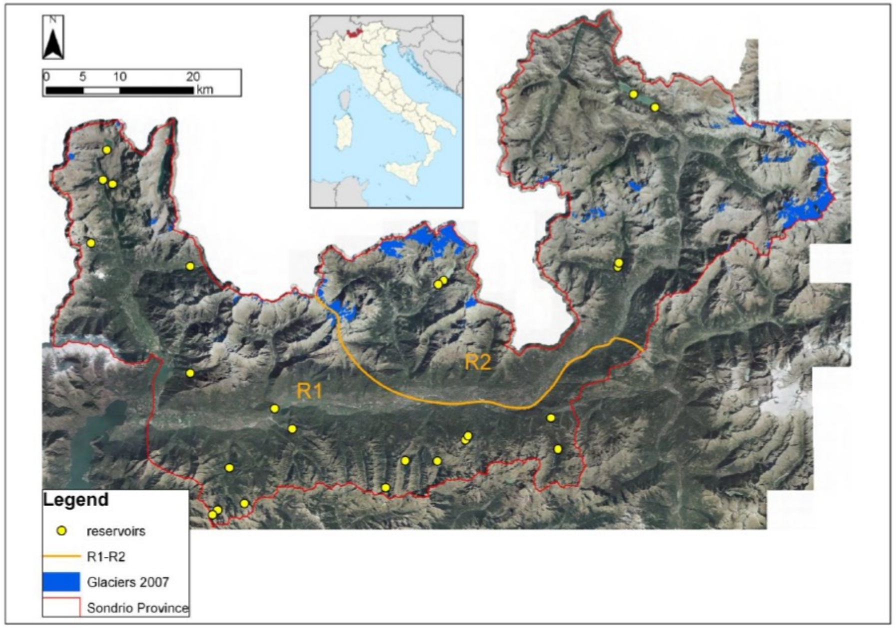
6) Soil erosion - HERASE Pr.

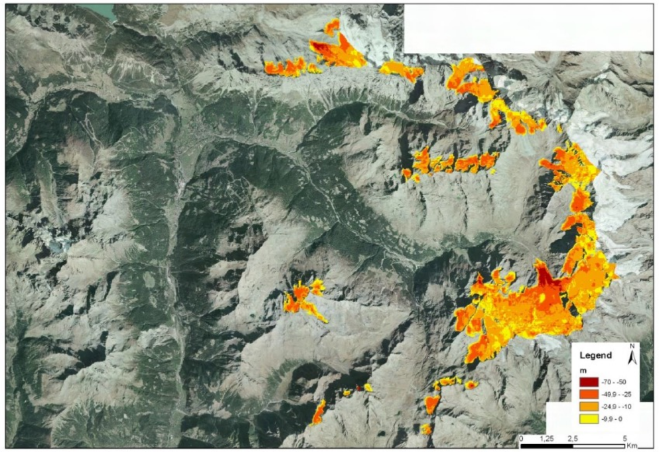
7) Mountain natural hazard – Aval-Risk Pr.

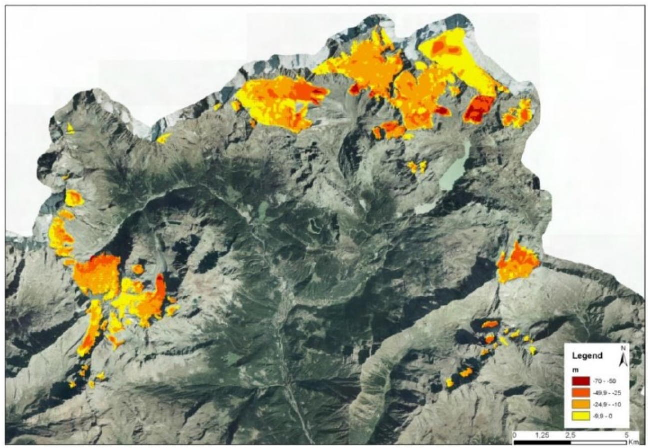
Hydropower production

Hydropower in Northern Lombardia

Map of glacier coverage (blue areas) in Lombardia Alps.
Yellow dots are the 25 major hydropower plants operating via impoundments in large reservoirs, with height > 10 m, and volume >10^6 m^3),

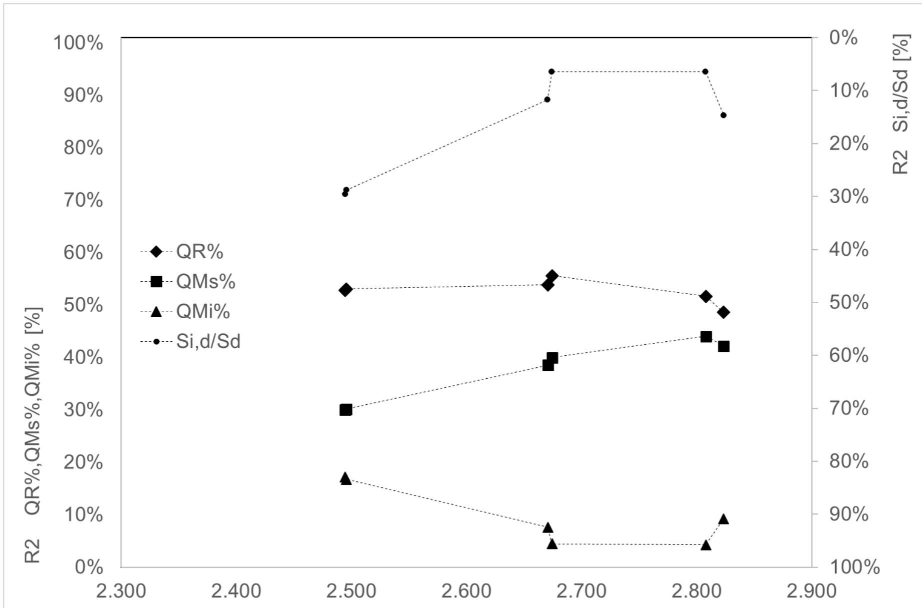






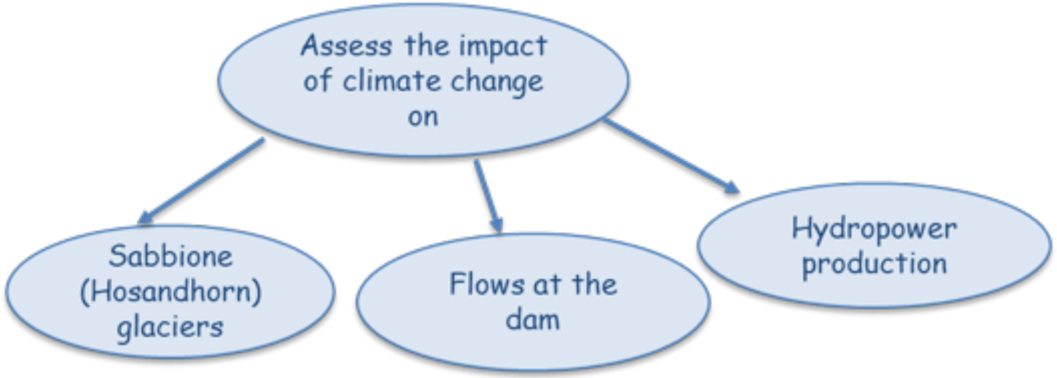
Thickness changes of glaciers in the Ortles Cevedale (upper), and in the Bernina-Disgrazia (lower) glaciers, 1981-2007

Share of rainfall Q_R%, snowfall QM_s%, ice melt QM_i% for hydropower production vs average altitude of contributing catchment. Region R2, Northern Valtellina



Hydropower production: one case study

Year of construction: 1949-1953
Height: 64 metri
Crown altitude: 2460 m a.s.l.
Volume: 26 mil. m^3 in 1953, 44 mil. m^3 now
Power production: 44 GWh/year



water

MDPI

Article

Hydropower from the Alpine Cryosphere in the Era of Climate Change: The Case of the Sabbione Storage Plant in Italy

Leonardo Stucchi, Giovanni Martino Bombelli, Alberto Bianchi and Daniele Bocchiola *

Department of Civil and Environmental Engineering DICA, Politecnico di Milano, L. da Vinci 32, 20133 Milano, Italy
* Correspondence: daniele.bocchiola@polimi.it

Received: 3 July 2019; Accepted: 30 July 2019; Published: 1 August 2019

check for updates

La diga del ghiacciaio, Ermanno Olmi, 1955.
https://www.youtube.com/watch?v=6WLgdNimrrA

Leo Stucchi: CGI Awardee for best Thesis in Glaciology, 2019

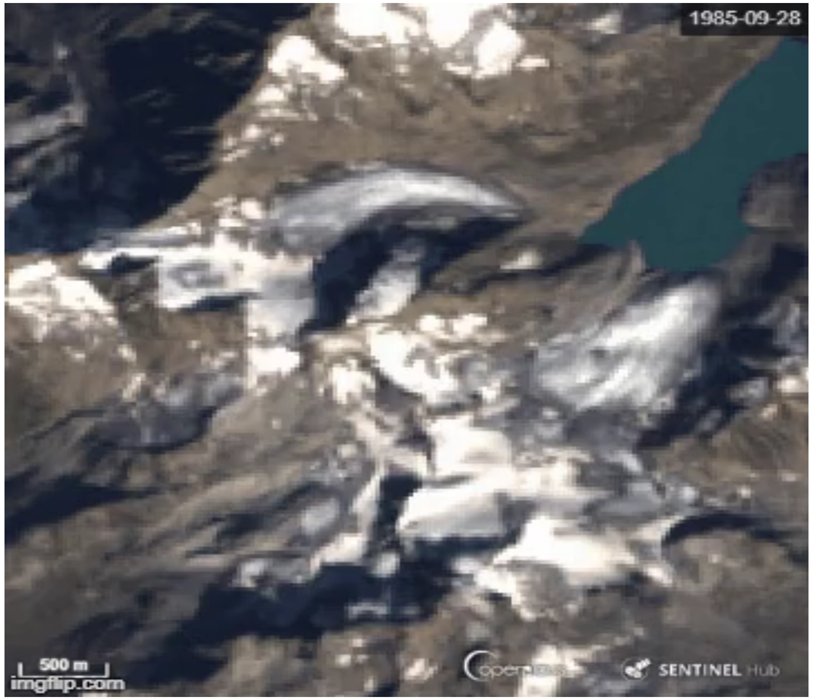
Sabbione (Hohsand) glacier

In swiss maps in 1898 one single body

In 1954 the glacier tongue dips into the lake…

During one century (1885-1987) retired ca. 1600

Since the '80s the glacier emerges from the lake.

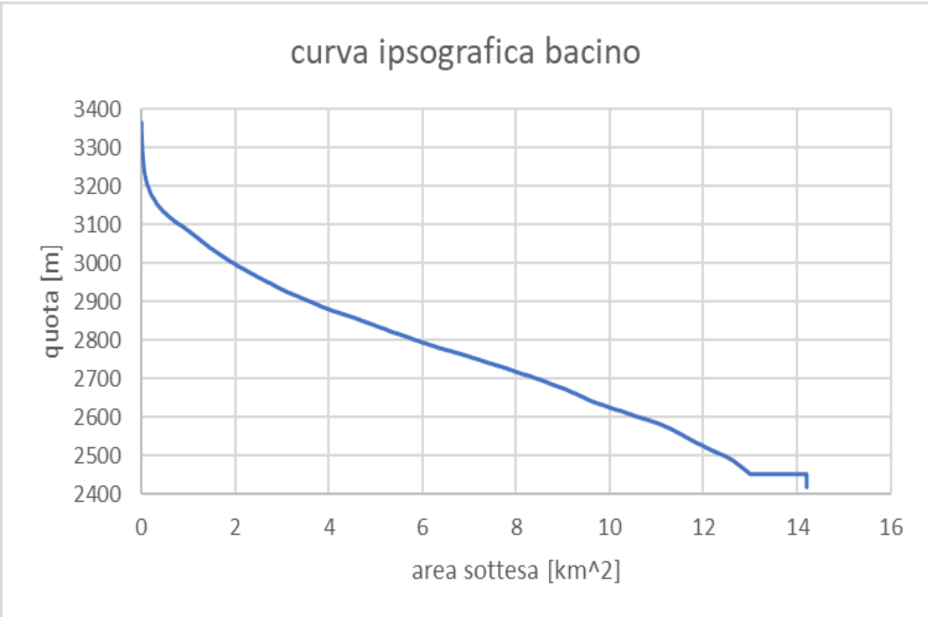


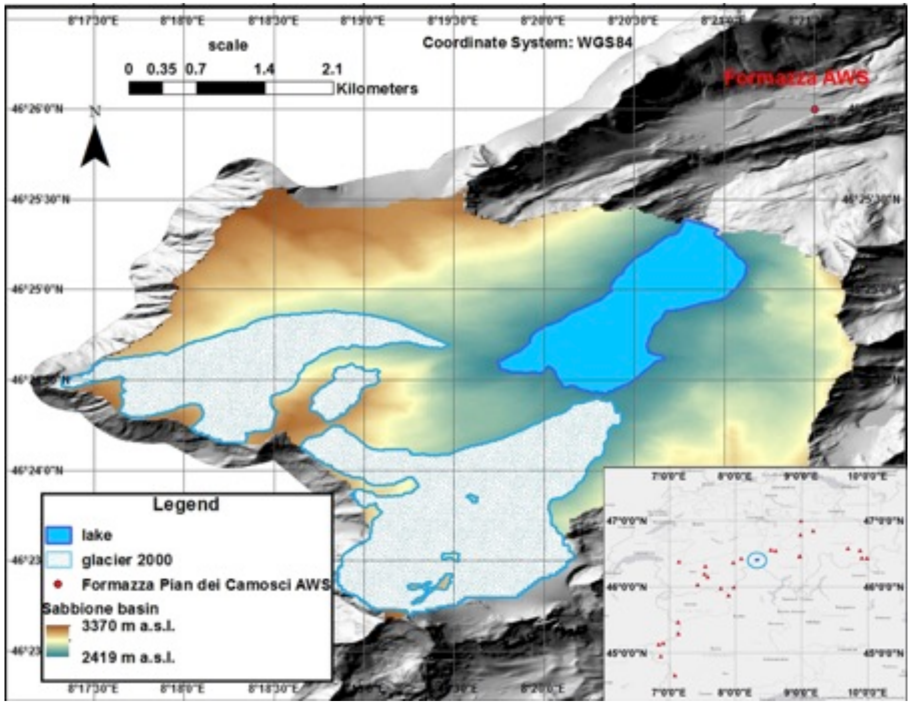
Sabbione glaciers' area, 1986-2011

Hydrological catchment, Sabbione dam

Digital terrain model → • Contributing area to Sabbione reservoir

A:14.5 km^2
Max alt: 3374 m a.s.l.
Min alt: 2454 m a.s.l.





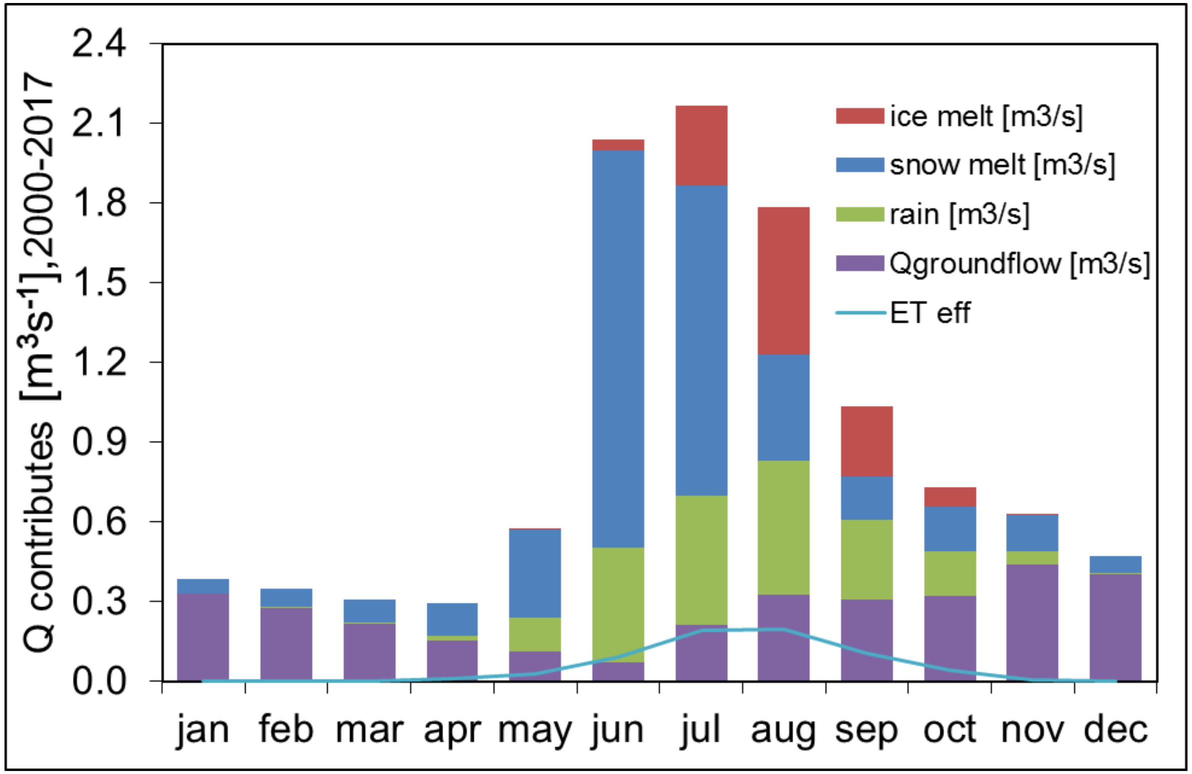
Sabbione reservoirs

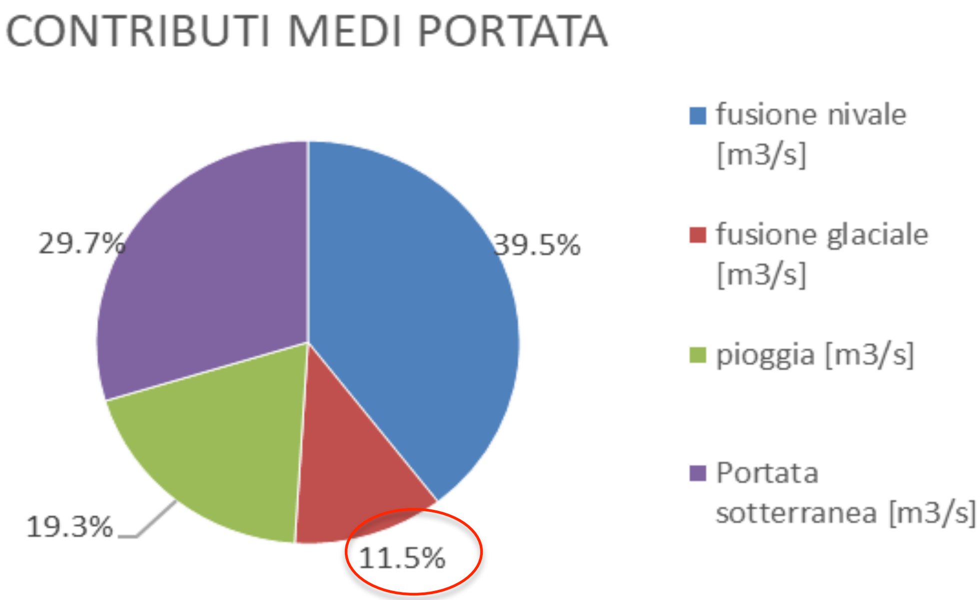
Inflow to the reservoir

Poli-Hydro model is used to simulate the glacier's dynamics, and the outflow to reservoir from the catchment

2000-2017 !

Mean flow is 0.902 m^3/s



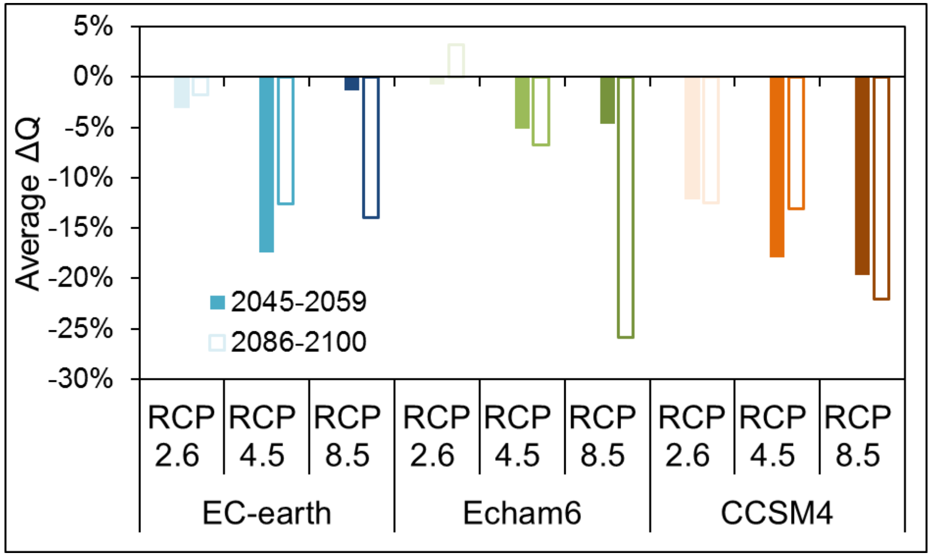


Flow shares

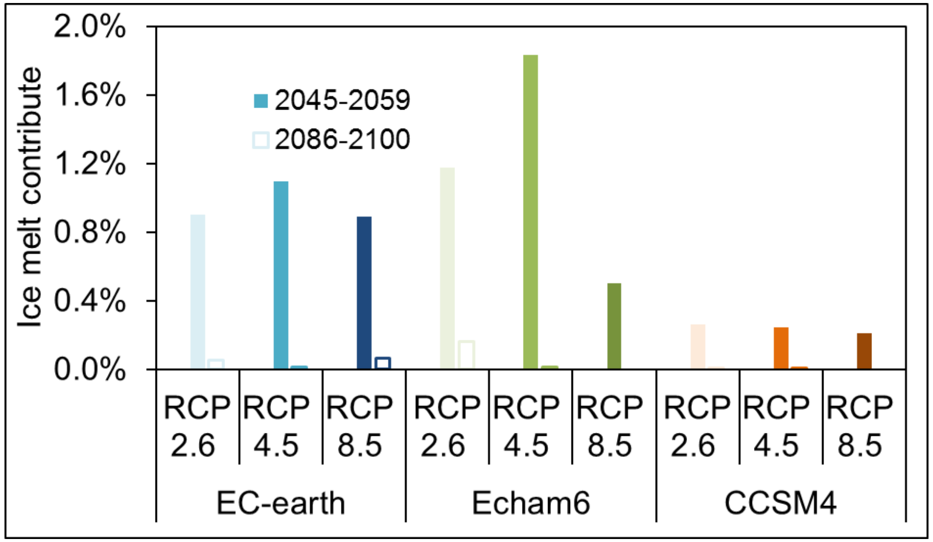
1) Water from ice melt covers ca. 12%
2) Water from (seasonal) snow melt covers ca. 40%

Projected inflow reservoirs

Stream flow is lower and lower decreases moving towards the end of century

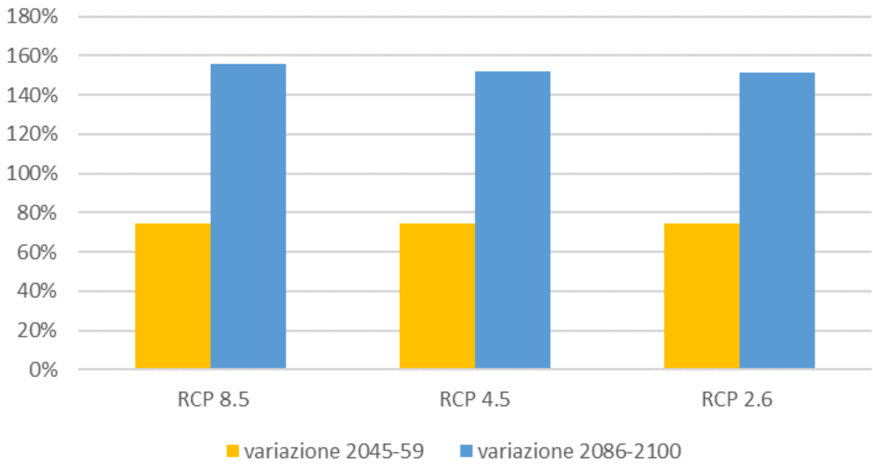


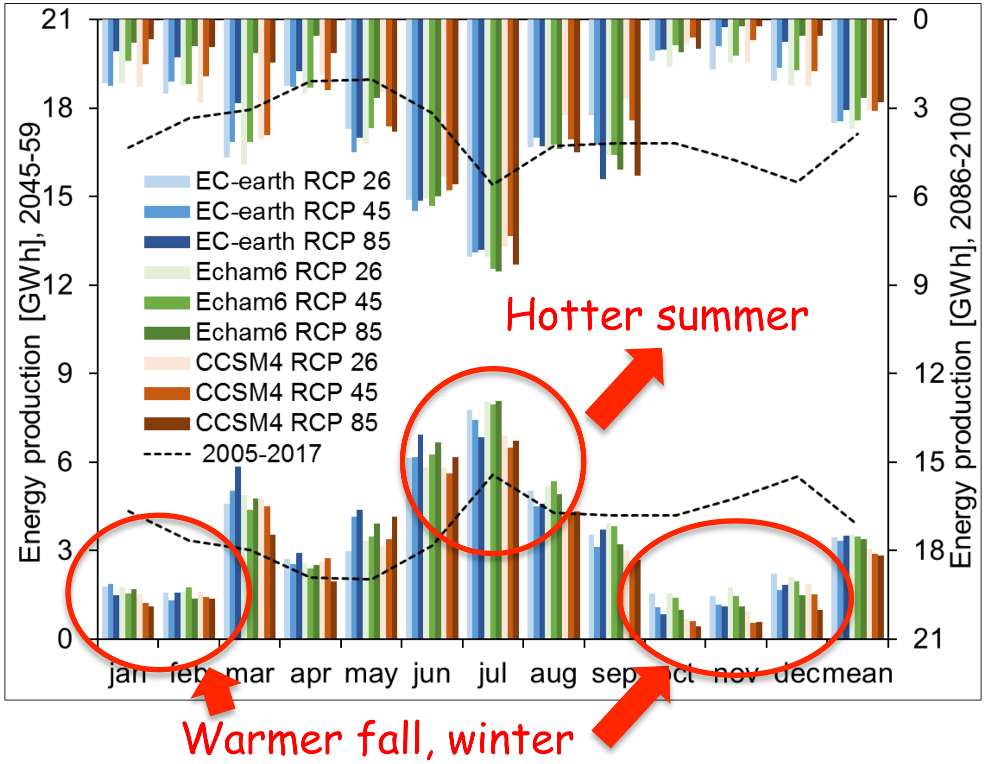
Ice flow contribution becomes smaller and smaller, null under some scenarios at 2100



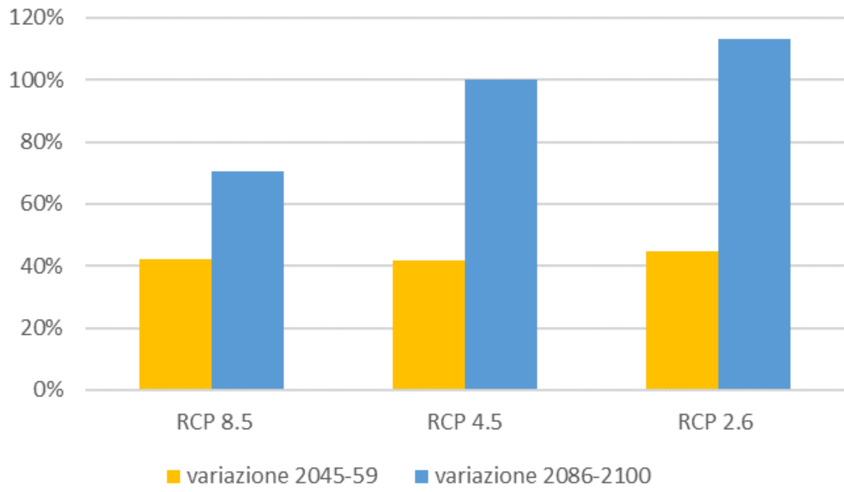
Future scenarios of production

% Changes in mean energy price

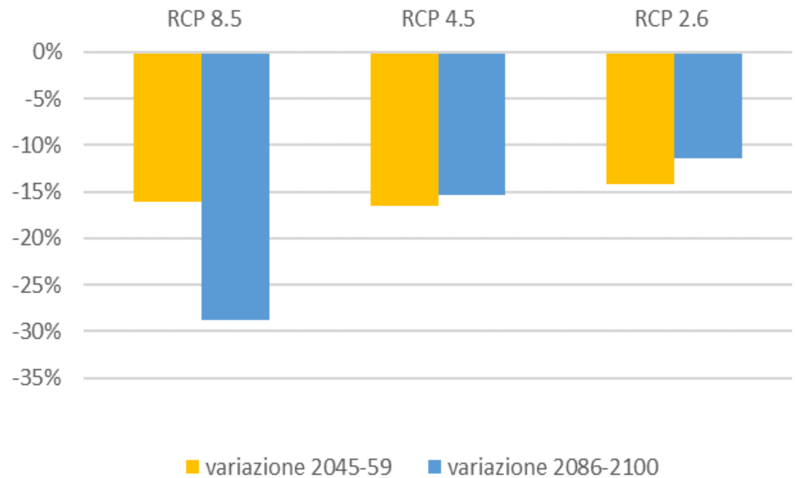




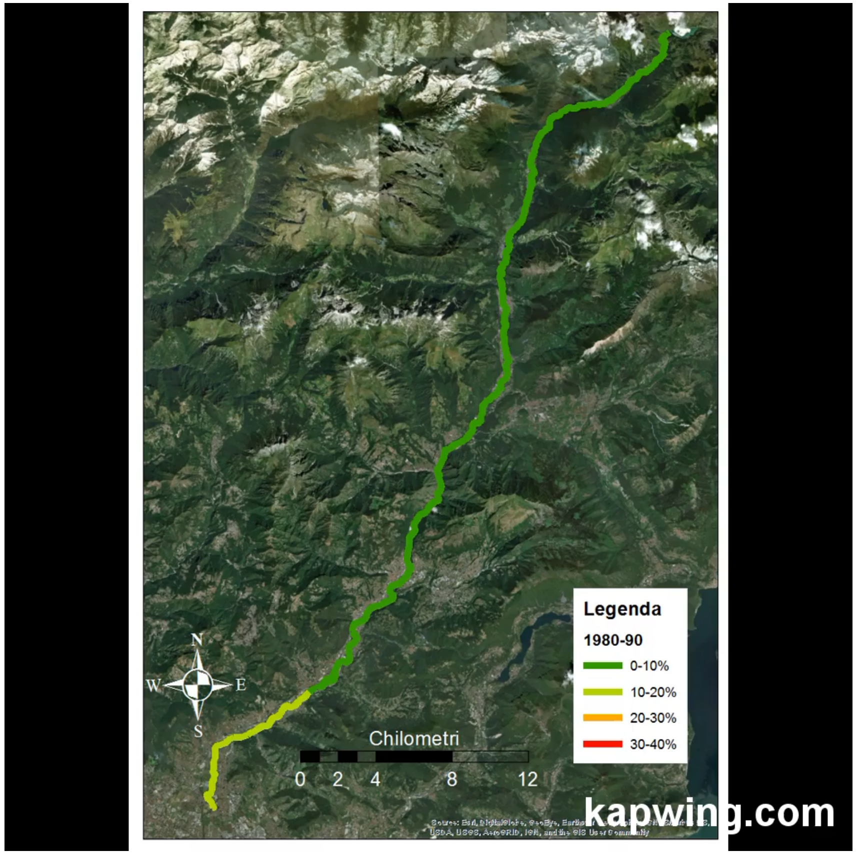
% Changes in mean yearly revenues



% Changes in mean energy production



River habitat, temperatures



# days $T > 15$ °C	<10%	10-20%	20-30%	30-40%
	Buono	Sufficiente	Scarso	Pessimo

Climate change and water in the mountains: lessons learned (the way forward)

High altitude catchments hydrology is complex in measuring, modeling, projecting. Field campaigns, albeit time consuming and harsh are needed, and worth.

Future climate variations could have large impact on the hydrological regime, and cryospheric cover of several continental cryospheric areas (in terms of discharge variation, and water amount stored in ice/snow layers).

At present continuous snow cover at relatively low altitude, provides shield to the ice. However the permanent snowline altitude would increase causing ice melting higher up.

Generally, discharge increase due to snow melting during the spring season will begin early, and larger floods wil occur in fall in lack of snowfall

Generally speaking, in the first half of the century ice ablation would provide a significant increase of water flows, however, when glaciers would down waste largely, a decrease in stream flows would be seen. The role of precipitation would be paramount important.

Monitoring future discharges is warranted to track variations, and design strategies.

The way forward

Adaptation (e.g. in water management and operation) is needed to modified hydrological cycle in terms of drinking/agricultural/hydropower needs, flood dynamics, and riverine ecosystems.

The methods developed (bottom/up) here could be used for regional assessment (top/down), even in large scale models (with feed-back)

The range of possible future precipitation changes under the IPCC is crucial, and need be explored, possibly narrowed.

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