High Summit LECCO 2013

October 23-25

POLITECNICO DI MILANO

SHARE paprika – Stations at High Altitude for Research on the Environment

EvK2CNR

UN Water World Water Day 2013 International Year of Water Cooperation

seed Social Economic Environmental Development

Impact of climate change on water resources in the water towers of Asia: the case of the upper Indus river

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&:

D. Bocchiola, A. Soncini, G. Confortola, E. Nana, A. Bianchi, G. Diolaiuti, C. Smiraglia, Umberto Minora, J. Von Hardenberg, E. Palazzi, A. Provenzale, E. Vuillermoz

High Summit LECCO 2013

High water resources under climate change (1)

Global warming has important consequences for the hydrological cycle, especially in regions where water supply is currently dominated by melting snow or ice. **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, amnd Himalaya, HKH (Aral lake, Amu-Darya and Syr-Darya, Indus, Ganges, Yangtze, Brahmaputra).

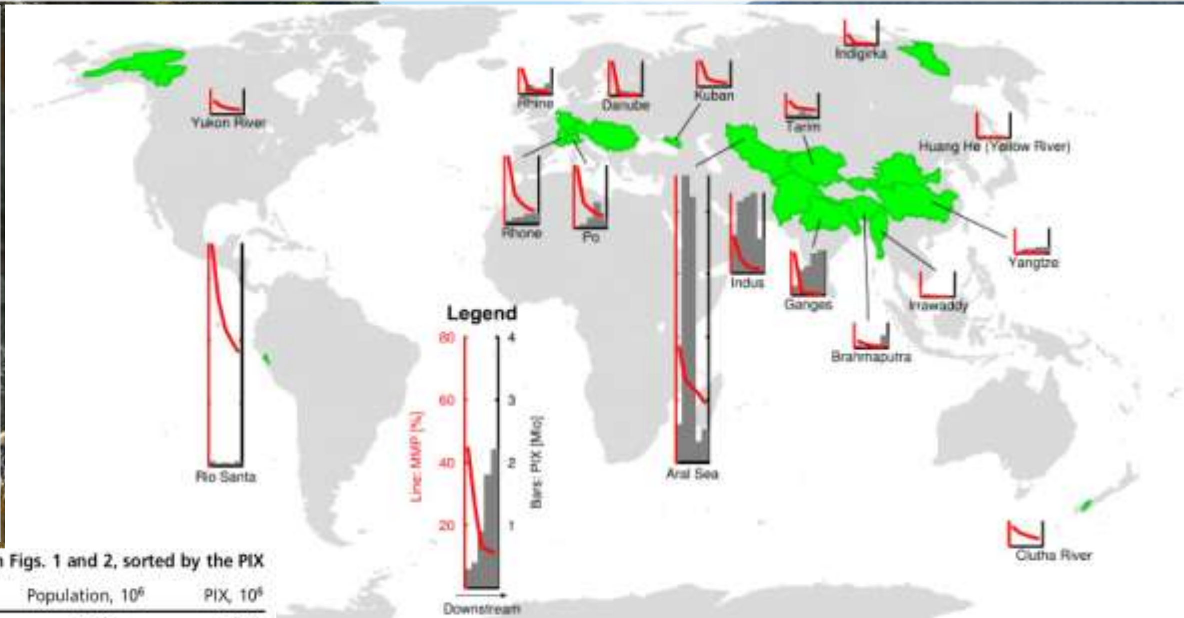


Table 1. Climatological and geographical characteristics of the river basins shown in Figs. 1 and 2, sorted by the PIX

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	448.98	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


PNAS

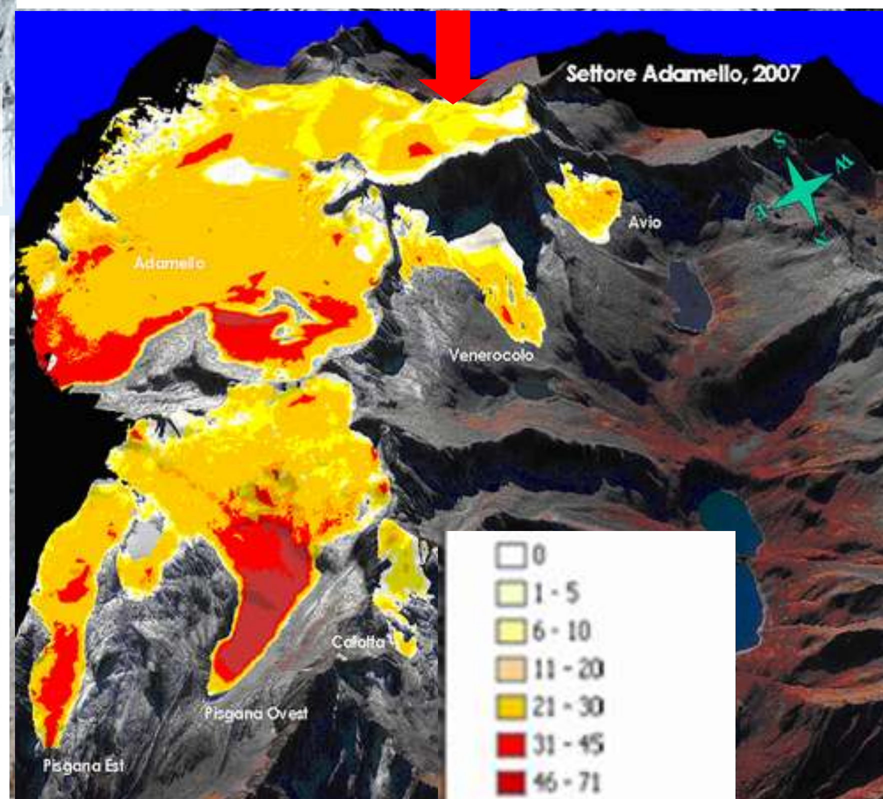
Contribution potential of glaciers to water availability in different climate regimes

Georg Kaser, Martin Großhauser, and Ben Marzeion

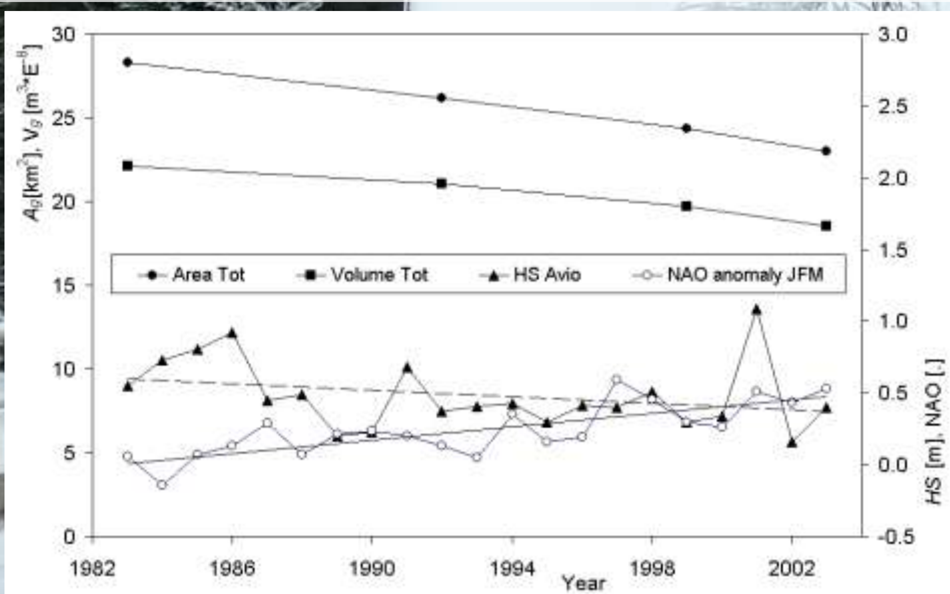
High water resources under climate change (2)

- Within the Alps ice bodies are retreating fastly, and snow cover is as well decreasing at a fast pace, thus affecting water resources at thaw

Estimated loss of thickness of Adamello glaciers during 1981-2007. Kind permission of Eng. Dario Bellingeri, ARPA Lombardia

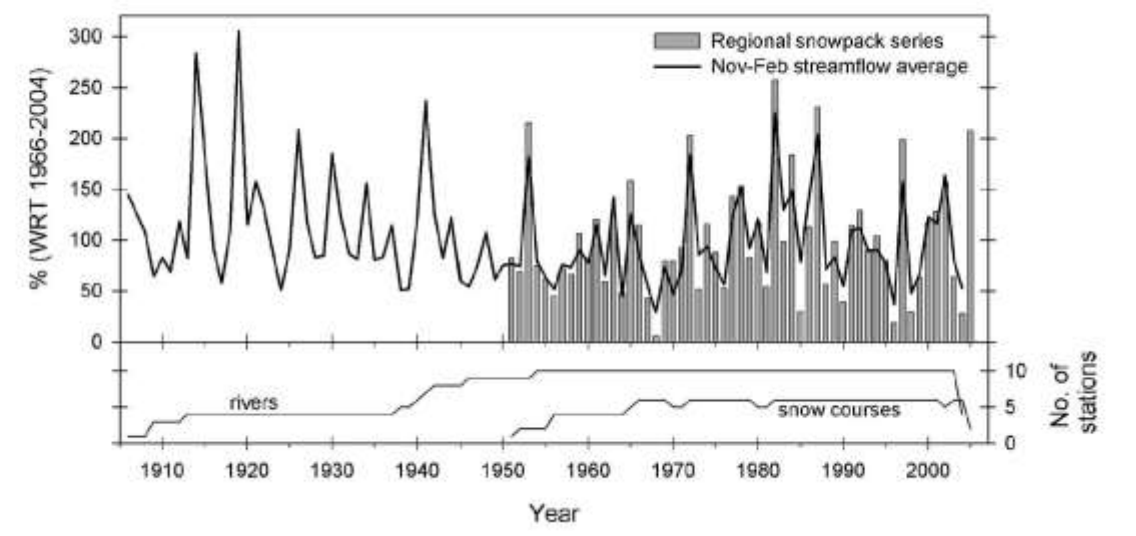


Snow depth HS, and NAO index against Adamello glaciers area and volume during1983-2003.

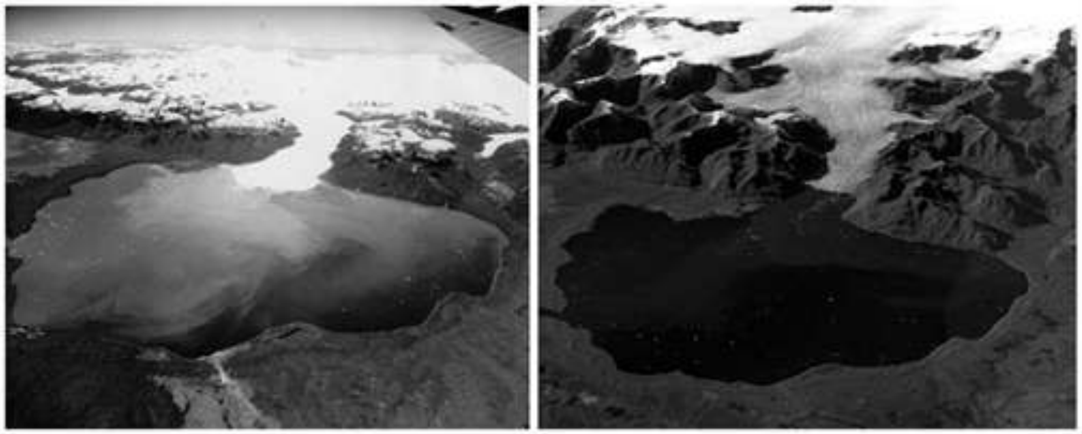


High water resources under climate change (2)

In the Andes, fast glacier and snow cover retreat is hampering water resources



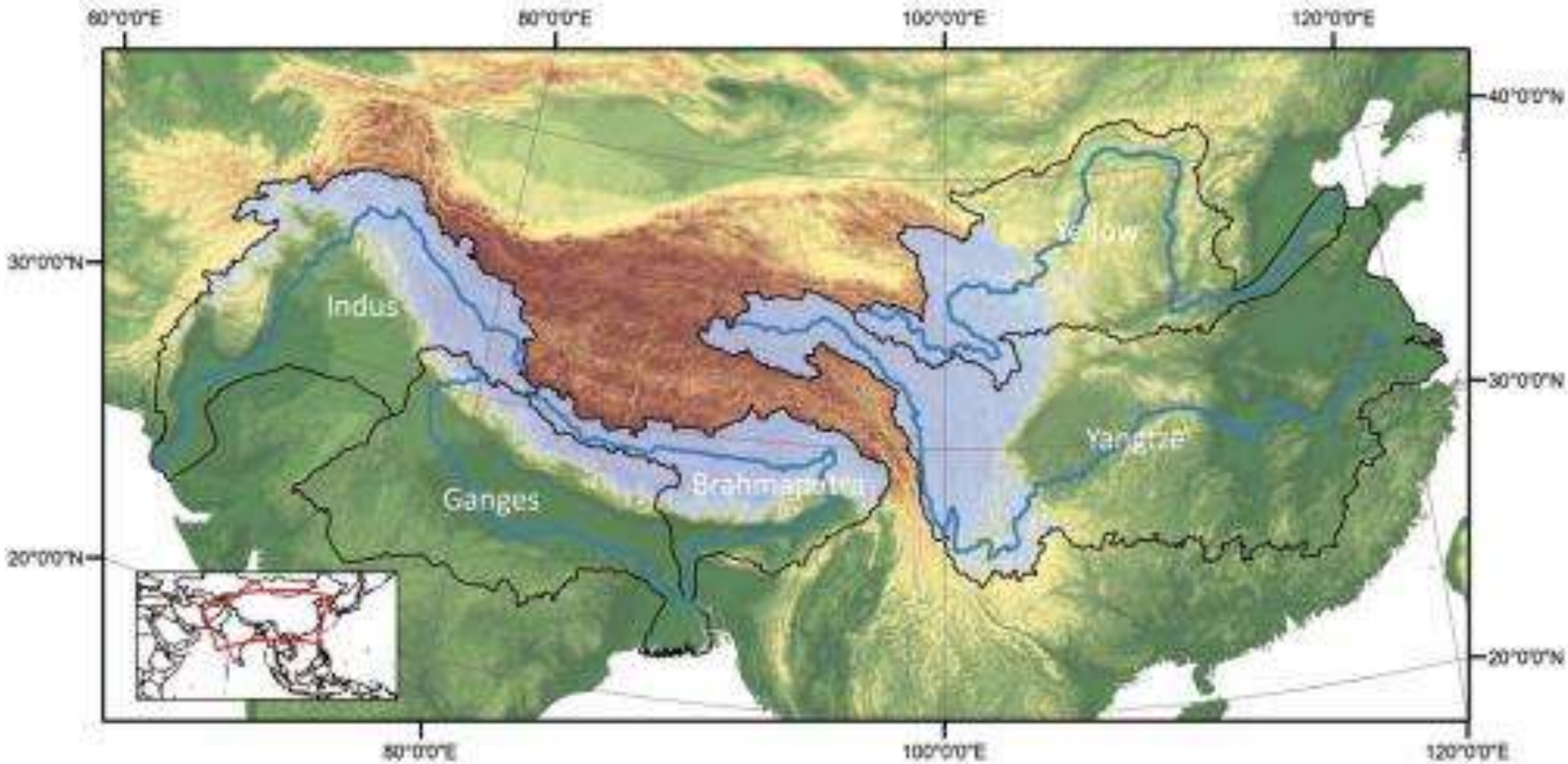
Change of Austral Summer discharges in the Andes of Chile and Argentina, 1905-2005. Grey bars max warter storage in snow. Dimensionless values referred to 1966-2004. Masiokas et al., 2006.



San Rafaél Aysen glacier 1945-2003. In: Rivera et al., 2009.

water resources from Asian water towers (1)

- **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**



water resources from Asian water towers (2)

While southern Himalaya is strongly influenced by monsoon climate, the meteo-climatic conditions of Karakoram suggest a stricter dependence of water resources upon snow and ice ablation.

Most recent observations of glacier fluctuations indicate that in the eastern and central HKKH glaciers are subject to general retreat, while stable or even positive ice mass balances and advancing glaciers have been reported in the Karakoram.

water resources from Asian water towers (3a)

the RONGBOK GLACIER (Everest, HIMALAYA)
LOST 106m (in depth) from 1921 to 2008

Shrinking glaciers may initially provide more melt water, but later their amount may reduced.

On the other hand, growing glaciers store precipitation, reduce summer runoff, and can also trigger local hazards.

water resources from Asian water towers (3b)

the front of BALTORO GLACIER (KARAKORAM) from 1954/1958 to 2013

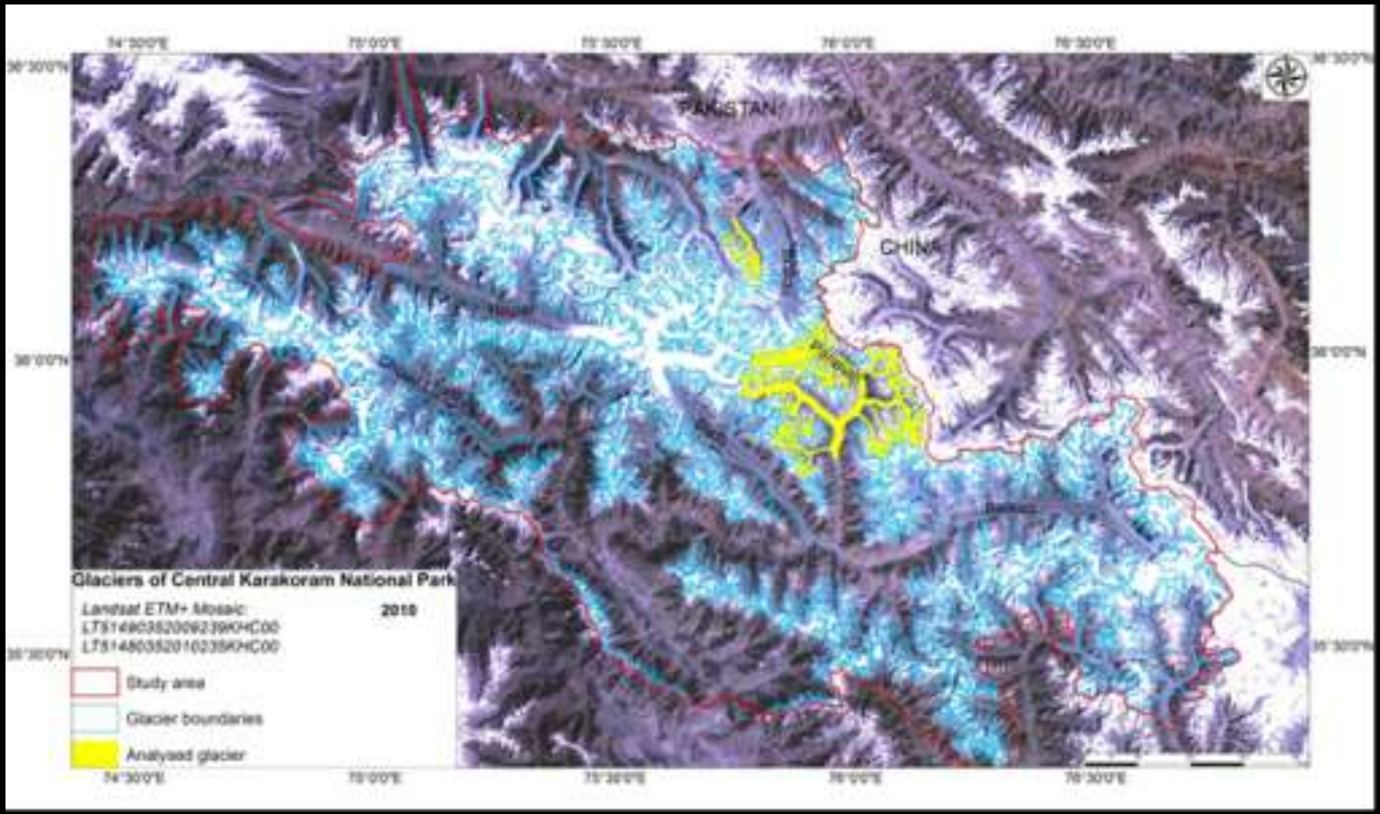
Shrinking glaciers may initially provide more melt water, but later their amount may reduced.

On the other hand, growing glaciers store precipitation, reduce summer runoff, and can also trigger local hazards.

water resources from Asian water towers (4)

Objectives of Share-Paprika, and SEED projects

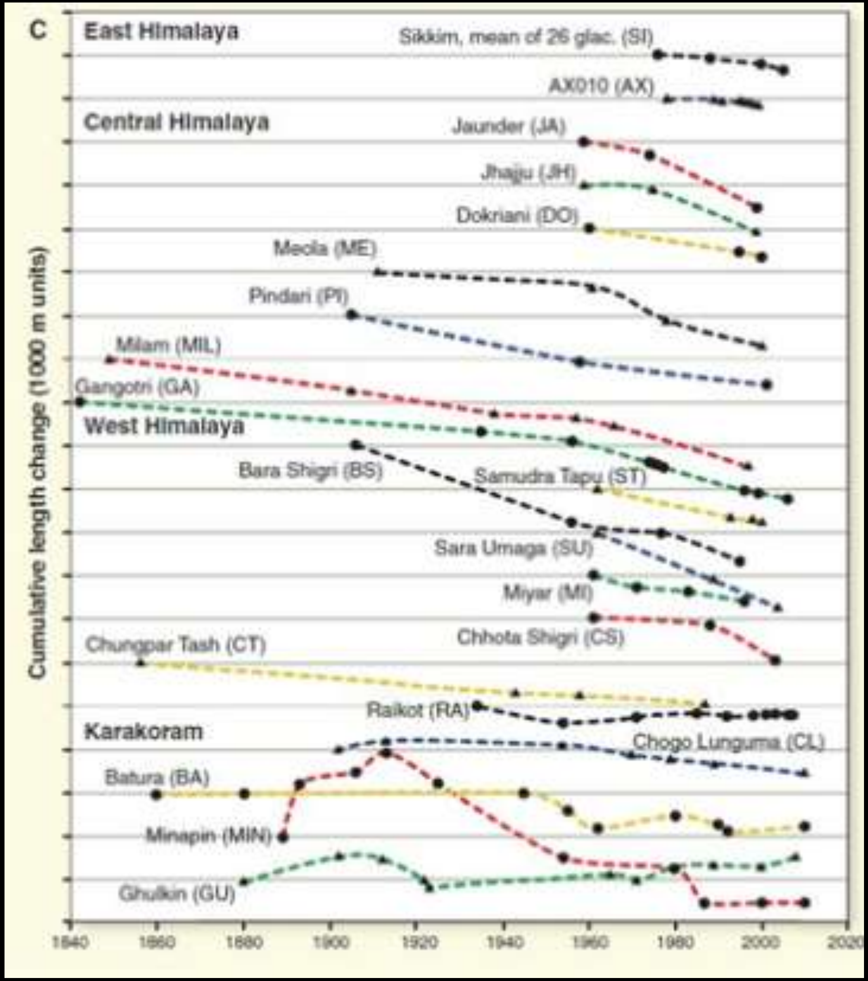
1. **Improving knowledge of physical processes underlying glacier dynamics, and hydrology of the Upper Indus Basin UIB**
2. **Modeling hydrological cycle of strongly snow and ice fed catchments in this area**



water resources from Asian water towers (5)

Objectives of Share-Paprika, and SEED projects

1. **…knowledge ….**
2. **…modeling ….**
3. **Providing medium and long range projections of UIB hydrology *(horizon: the end of the XXI century)***
4. **Set up strategies for monitoring and modelling the hydrologic and, mainly, cryospheric cycle in the specific case study area of Central Karakoram National Park, CKNP**



PAPRIKA

Mission

The Hindu Kush-Himalaya-Karakorum region includes the sources of several river basins that are widely fed by merging glaciers and seasonal snow, representing a source of water for hundreds of thousands of people in India, China, Pakistan and Nepal

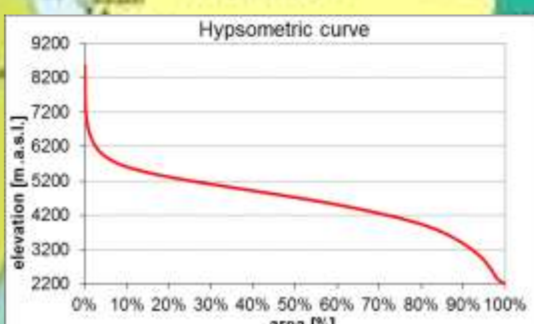
CryosPheric responses to Anthropogenic PRessures in the HIndukush-Karakoram-HimalayA regions: impacts on water resources and Availability

The PAPRIKA KARAKORUM Project focuses on current and future evolution of the cryosphere system in response to global and regional environmental changes and their consequences on water resources in main landscape units of PAKISTAN

Any change in water regime of HKKH region and in water availability could have critical consequences on local people, whose lives are strongly dependent upon these rivers

Case study: Shigar basin, PAKISTAN

The Shigar river basin



Area [km²]	6921
Perimeter [km]	785
Mean elevation [m s.l.m.]	4612
Min elevation [m s.l.m.]	2142
Max elevation [m s.l.m.]	8561
Elevation range [m]	6419
Main stream lenght [km]	125

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 Analysis

Available dataset

Field campaigns in years from 2011 to 2013

Daily flow at Shigar
April 2011-NOW

Daily flow at Paiju
Jun 2012-NOW

Ablation stakes
Summer 2011 - 13

In-situ Activities

Installation of hydrometric stations

Shigar gauge station (ultrasonic sensor) - April 2011

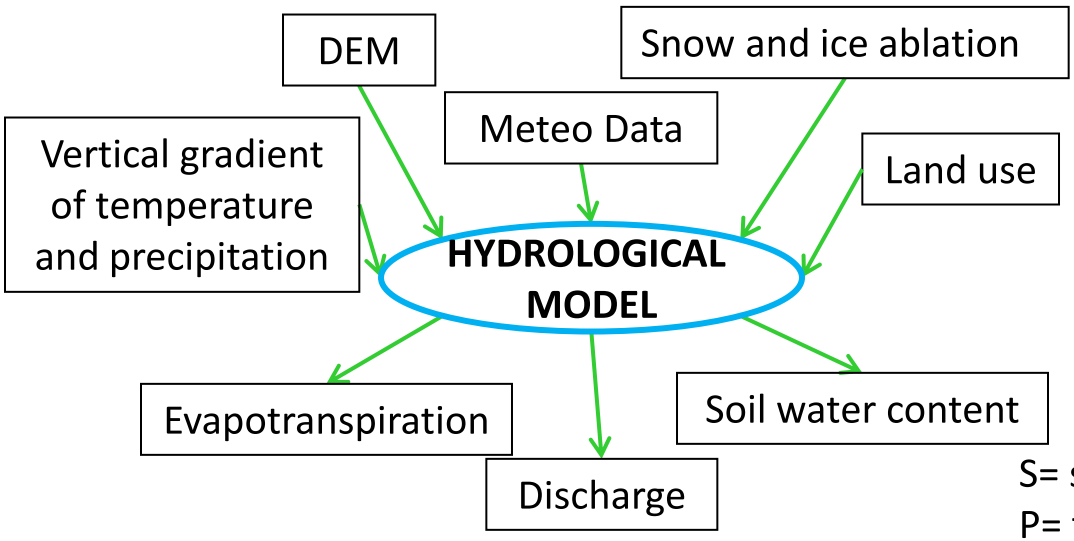
Altitude	2221 m a.s.l.
Watershed area	6923 km^2
Datalogger	Campbell Scientific - CR200X
Sensor	sonic sensor Vegason 63, 4-20 mA, 24V
Power supply	solar panel 20W + battery Pb 12V 40 Ah

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 hydrologic model



Simplified ice flow model

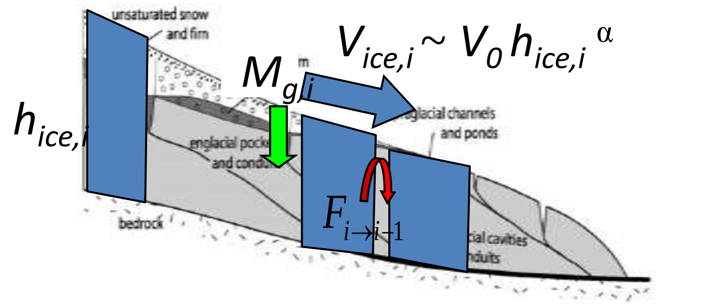


Fig. 2. The hydrological systems and locations of water storage in a temperate glacier (modified from Röthlisberger and Lang, 1987).

S= soil water content

P= total precipitation (rain and snow)

M_s= snow melt

M_g= ice melt

ET= evapotranspiration

Q_g= groundwater flow

Runoff production:

Q_s= superficial flow

S_{max}= max soil water content

Daily mass balance equation

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

Daily storage-outflow equation

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

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

Hydrol. Earth Syst. Sci., 15, 1–17, 2011
www.hydrol-earth-syst-sci.net/15/1/2011/
doi:10.5194/hess-15-1-2011

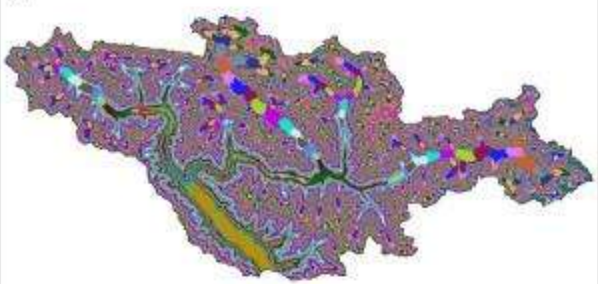
Hydrology and Earth System Sciences

Prediction of future hydrological regimes in poorly gauged high altitude basins: the case study of the upper Indus, Pakistan

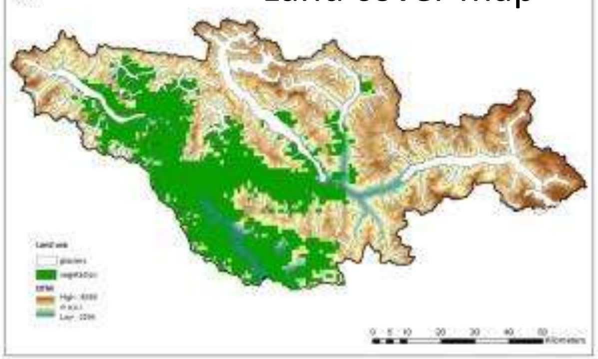
Hydrologic model

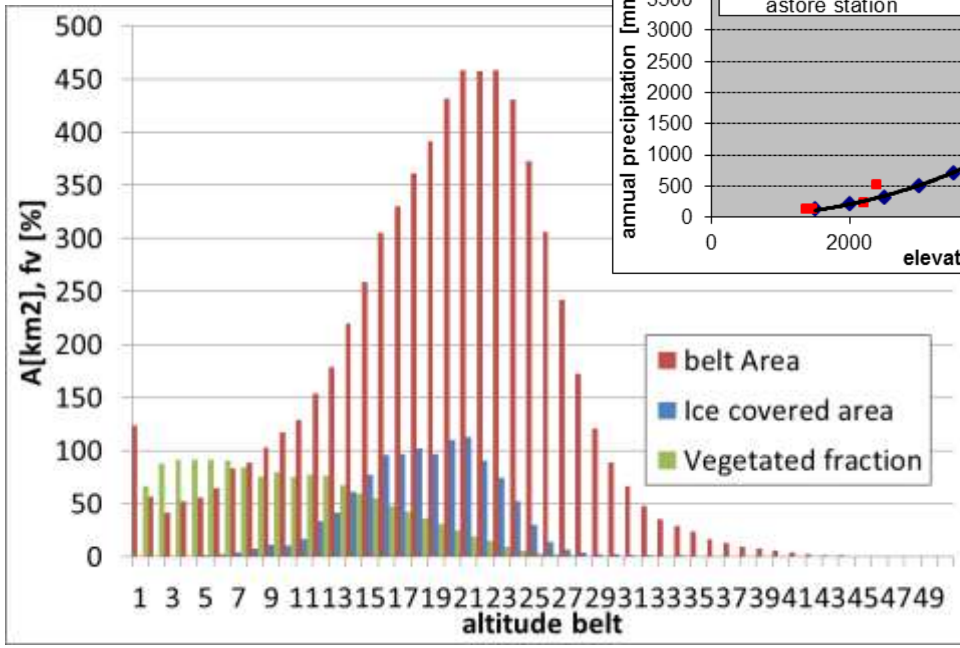
Input

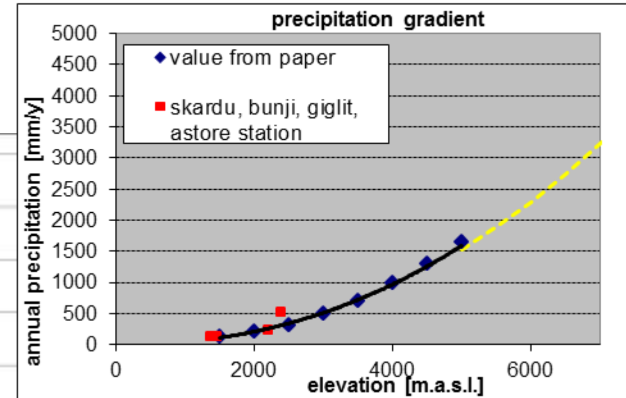
50 equispaced altitude belts



Land cover map







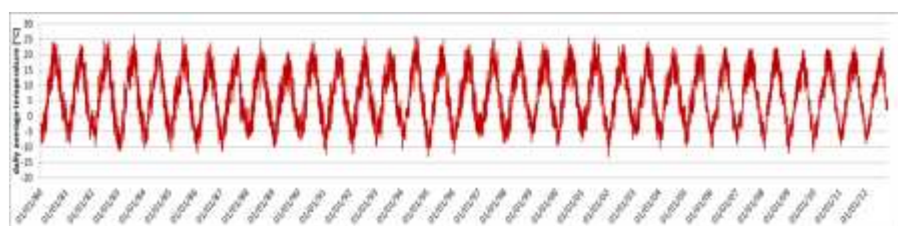
Winiger M.et al., 2005.

Available meteorological data

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

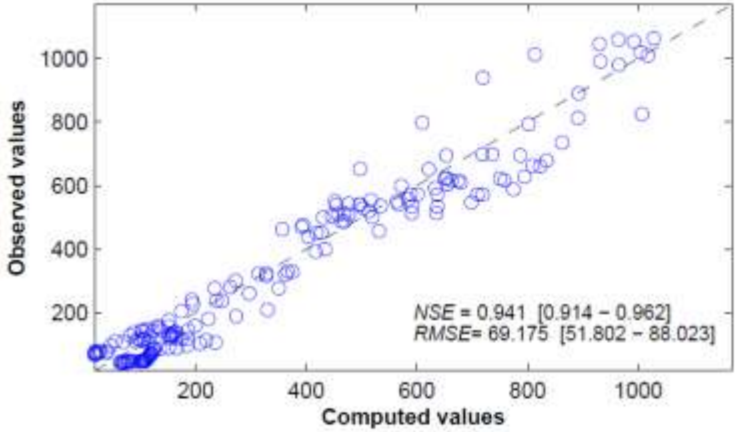
Monthly mean flow data available at Shigar from 1985 to 1997

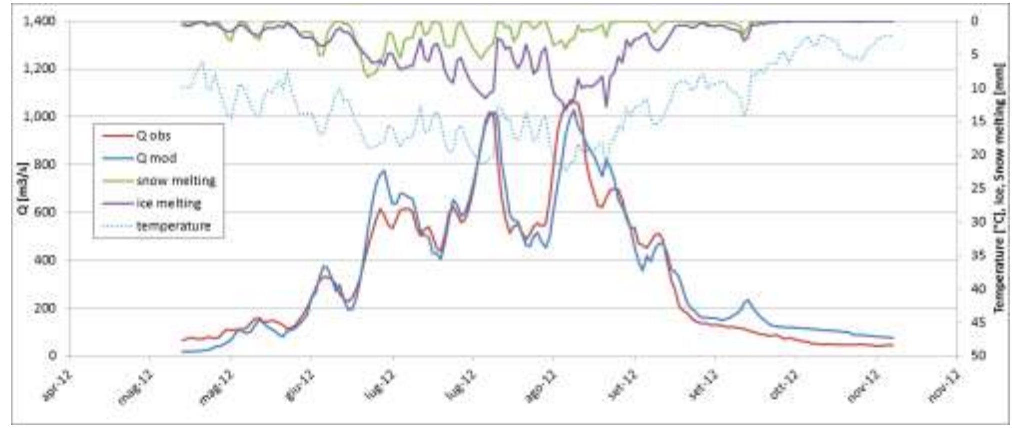
Statistical downscale on monthly Astore data based on daily Askole data

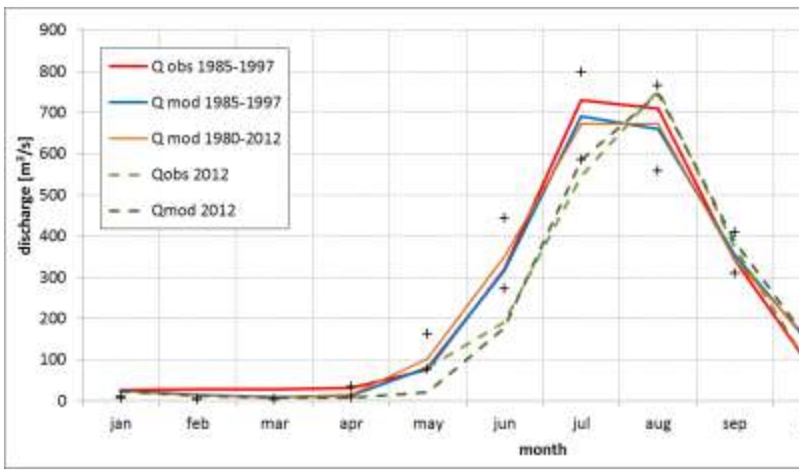


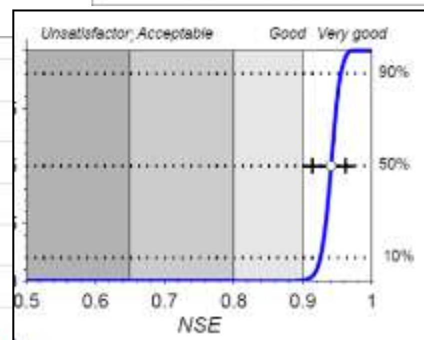
Hydrologic model

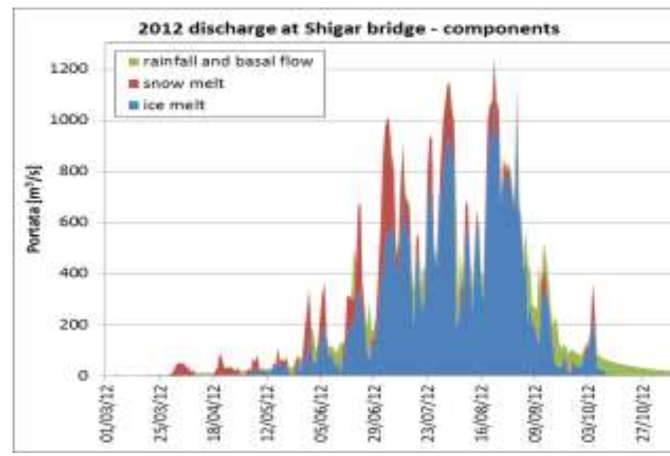
Calibration 1985-1997 monthly data at Shigar









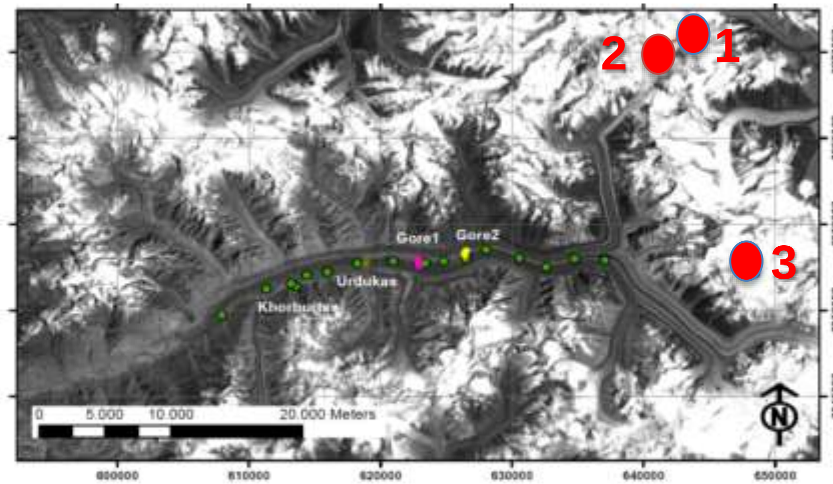


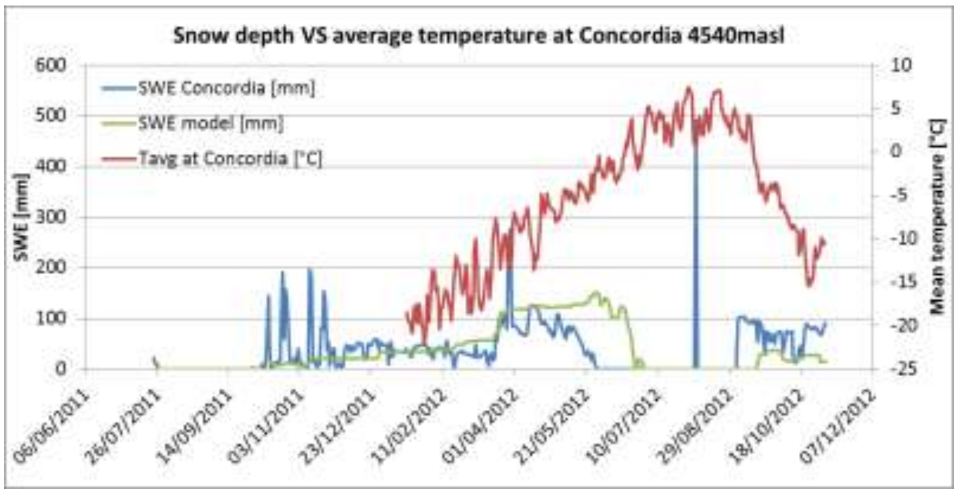
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	average
observed 1985-1997	26.07	27.76	28.55	31.81	76.47	319.42	729.21	710.09	343.53	78.71	44.13	29.05	**203.73**
model 1985-1997	24.05	13.43	8.72	12.78	81.27	316.22	690.03	659.95	355.54	134.27	82.60	46.61	**202.12**
model 1980-2012	24.07	13.23	8.49	14.60	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**

Hydrologic model

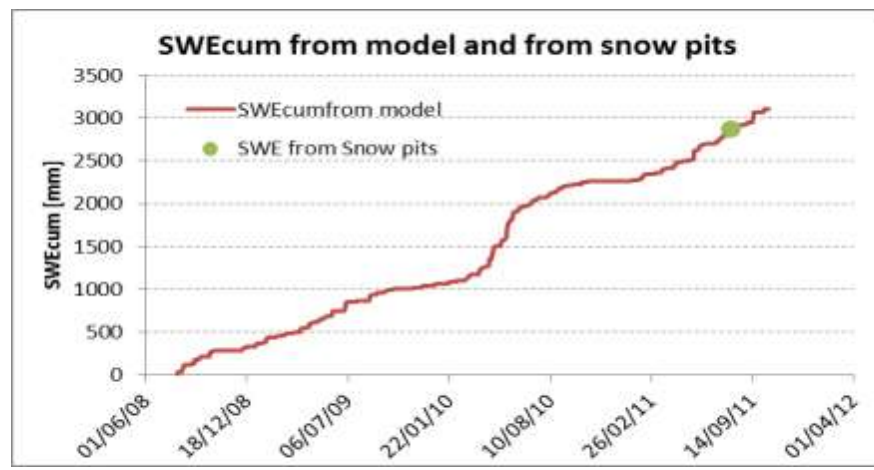
Calibration 2011 snow pits and 2012 nivometer

The comparison of **Concordia** (about 4700 m amsl) **nivometer data** (2012) versus **model SWE estimates** at the same elevation/belt need some arrangement





Snow pits data from summer 2011 field campaign



Comparison between 3 years accumulation SWE from model and summer 2011 snow pits

recent climate in the area

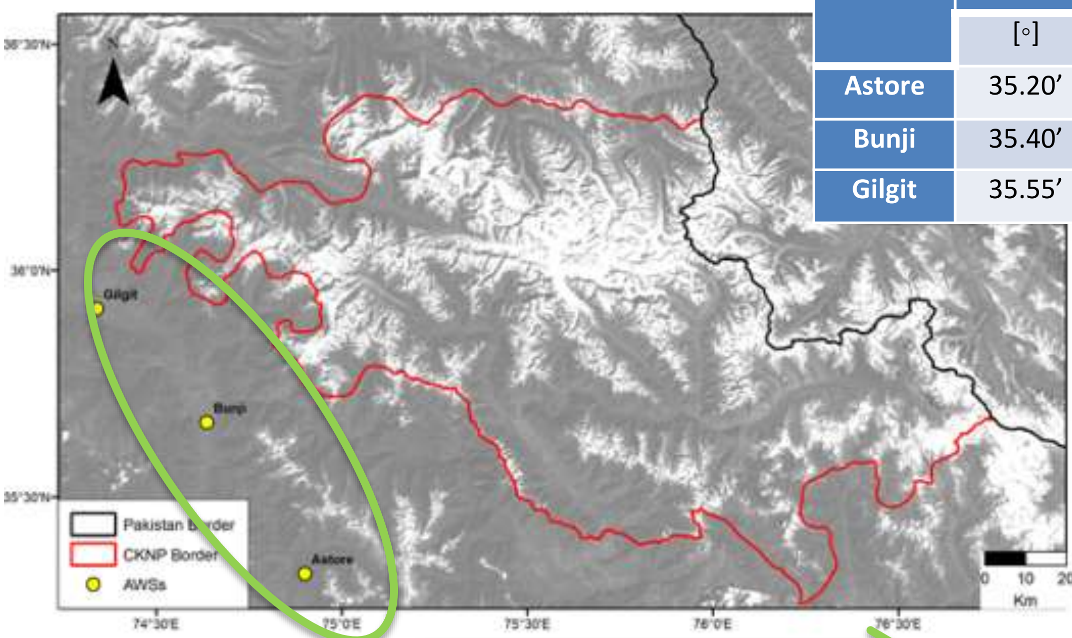
PAPRIKA investigated seasonal meteorological variables, provided by the Pakistan Meteorological Department, from the three nearest stations to target area, e.g.:

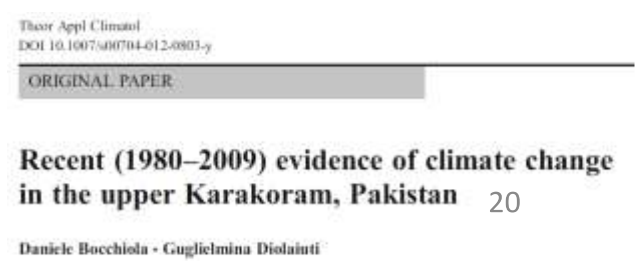
- monthly amount of precipitation Pm (mm),
- monthly number of wet days Dw,
- monthly average of the maximum and minimum day-time air temperature Tmax (°C), Tmin (°C).

Station elevation ranges from 1372 m amsl (Bunji) to 2168 m amsl (Astore), rather low against altitude of the region and precipitation gradients

Looking for trends via linear regression (LR), and Mann-Kendall (MK) test, traditional and progressive (backward-forward).

Station	North	East	Altitude	Average (P_Y)	Average (T_Y)
	[◦]	[◦]	[ma.s.l.]	[mm]	[◦C]
Astore	35.20’	74.54’	2168	486	9.8
Bunji	35.40’	74.38’	1372	161	17.3
Gilgit	35.55’	74.20’	1460	137	15.8




Theor Appl Climatol
DOI 10.1007/s00704-012-0803-y

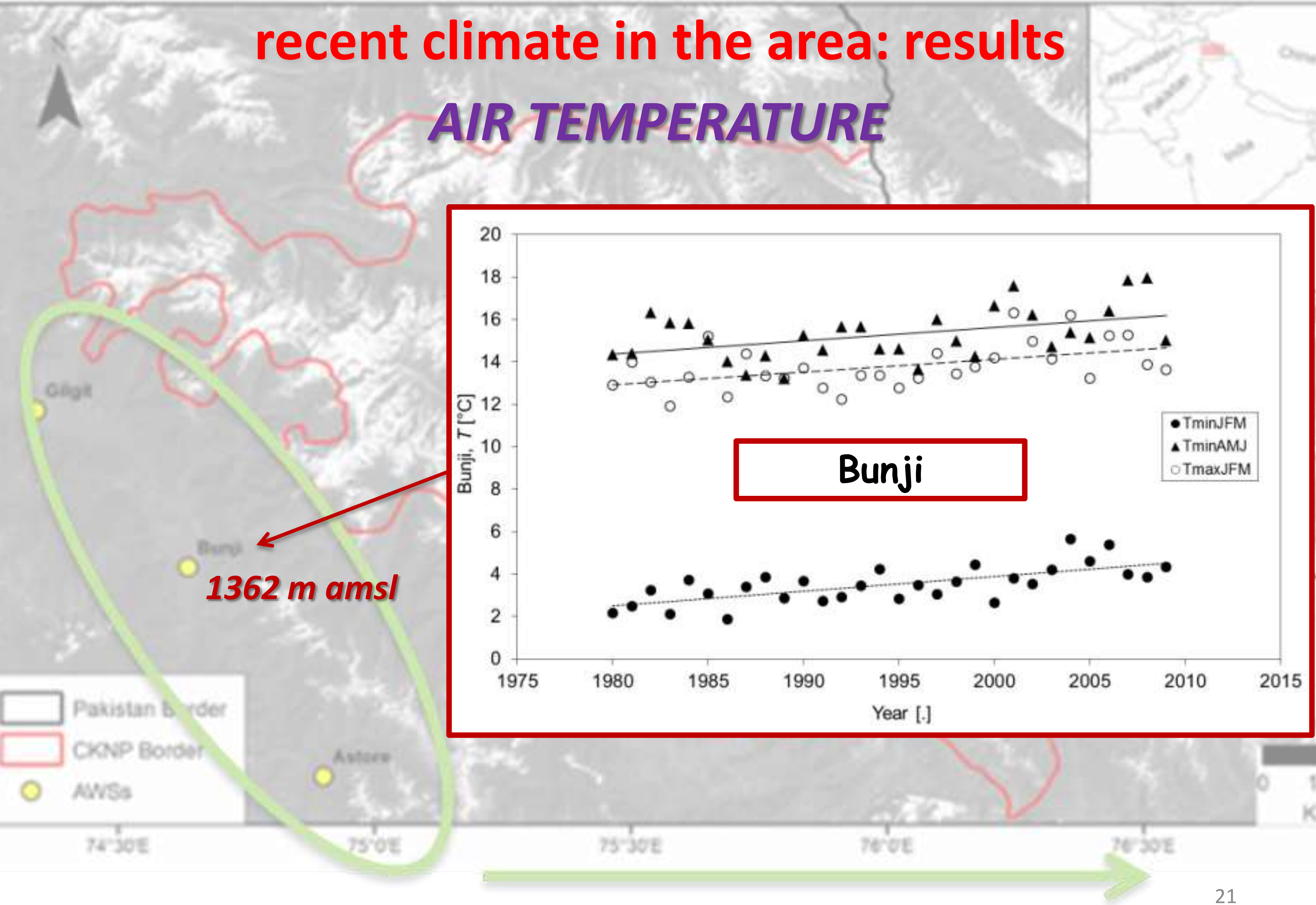
ORIGINAL PAPER

Recent (1980–2009) evidence of climate change in the upper Karakoram, Pakistan

Daniele Bocchiola · Guglielmina Diolaiuti

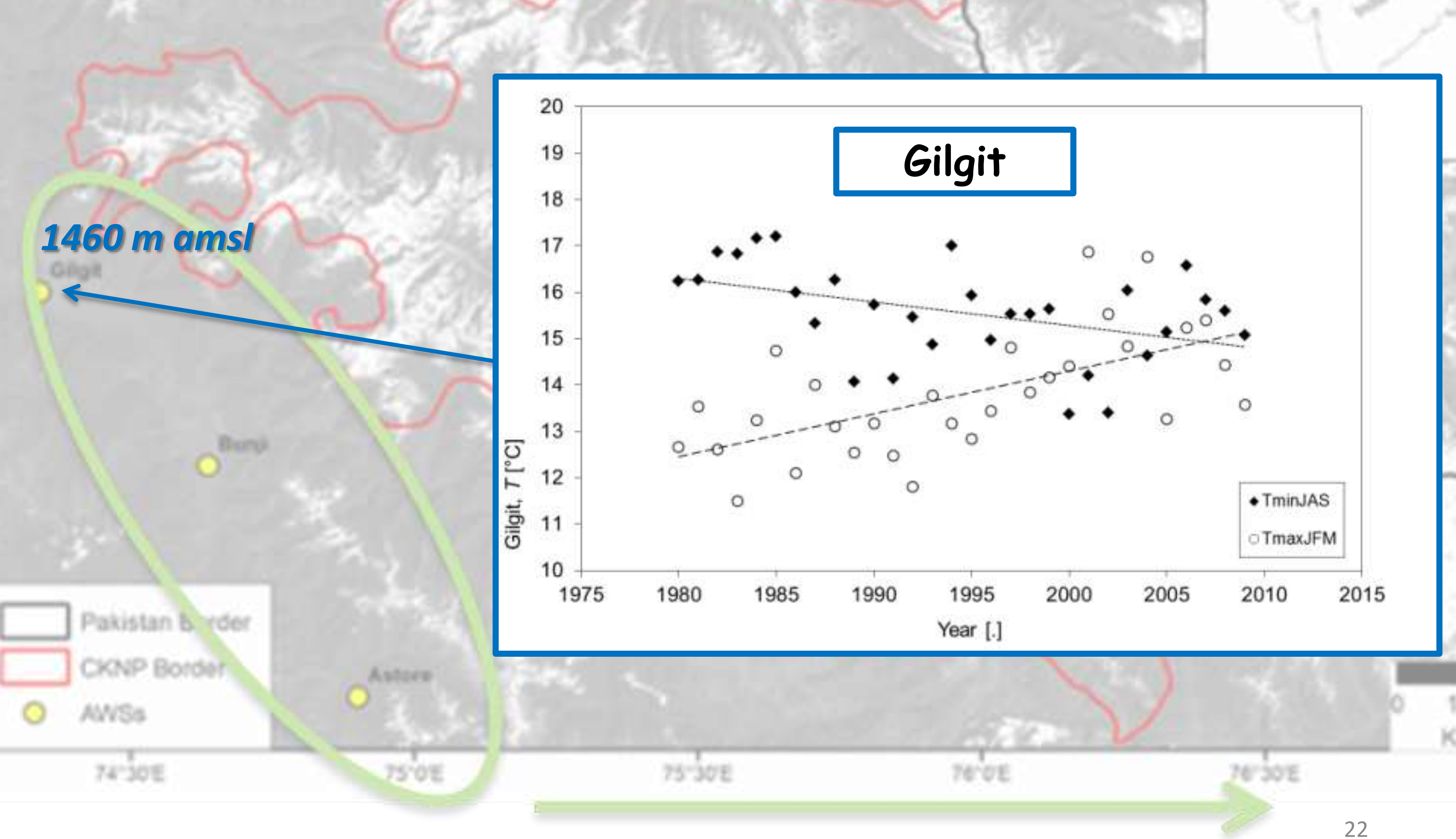
recent climate in the area: results

AIR TEMPERATURE



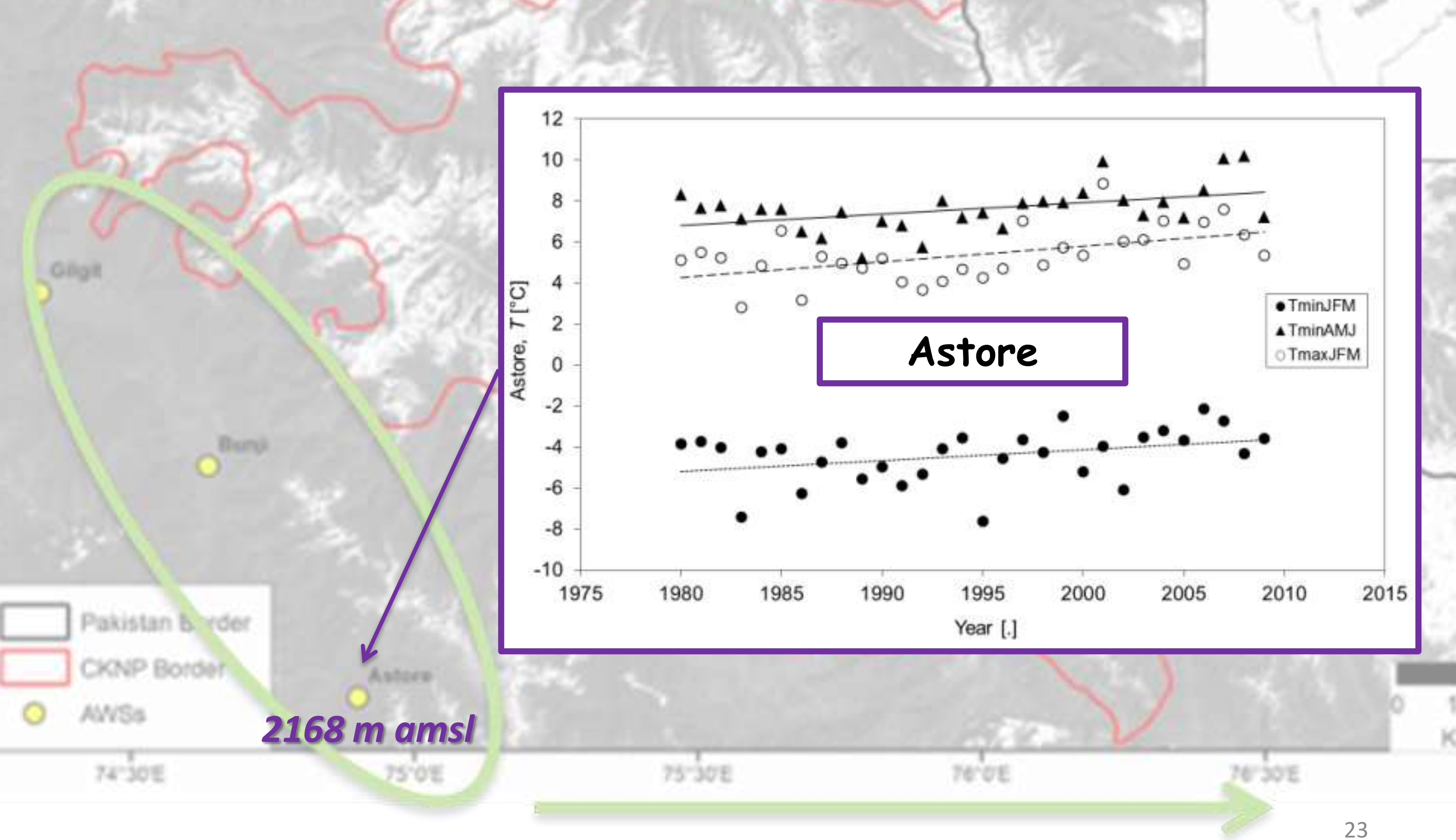
recent climate in the area: results

AIR TEMPERATURE



recent climate in the area: results

AIR TEMPERATURE



recent climate in the area: results

AIR TEMPERATURE

Minimum Daily Temperature T_{min} , on average:

- increases significantly at **Astore** (JFM, AMJ, since 1999-2002), and at **Bunji** (Y, JFM, AMJ, OND, since 1997-2003)
- at **Gilgit** T_{min} decreases significantly during Summer (JAS, since 1986), and not-significantly in Fall and yearly

Maximum Daily Temperature T_{max} , on average:

- increases significantly at **Astore** (Y since 1998, JFM since 2000)
- also at **Gilgit** significant T_{max} increas is are observed (Y, JFM, since 1995, OND, since 1991)
- while **Bunji** displays significant T_{max} increase only in winter (JFM, since 1997) and a non-significant decrease in JAS.

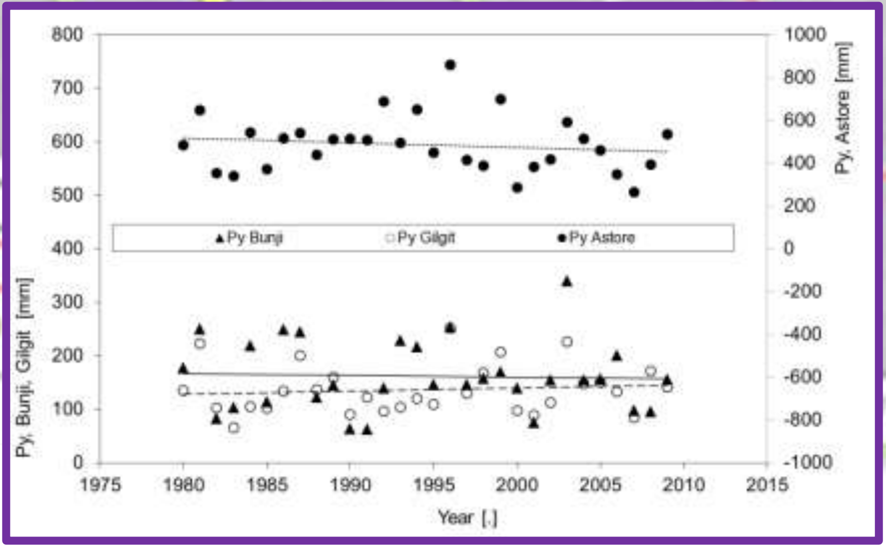
recent climate in the area: results
PRECIPITATION

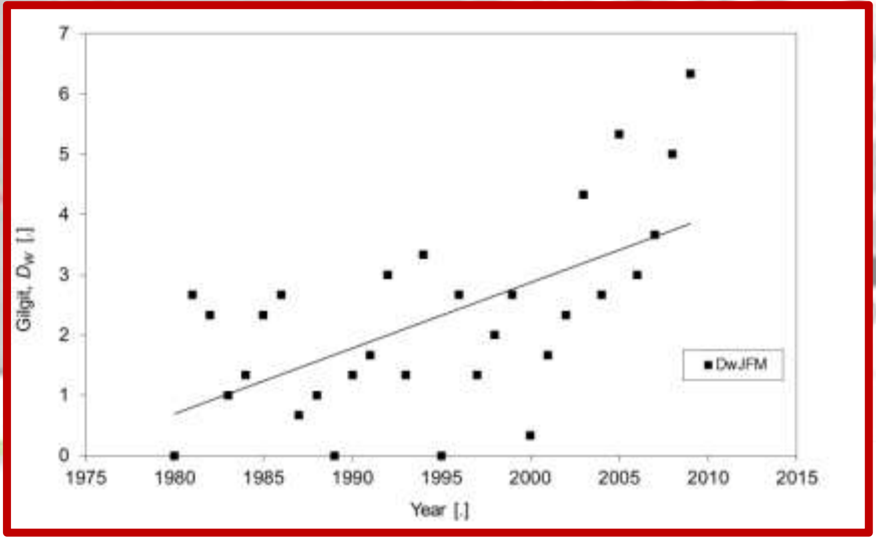
Annual and Seasonal Precipitation P_m , is **substantially stationary**

- No trend in station data

Wet spells D_w , display **some specific substantial trend**

- Number of wet days Dw increases at Gilgit (yearly, since 2001, JFM, no clear onset), and at Astore (JAS)
- But, non-significant decreasing values occur at Bunji





recent snow cover in the area

PAPRIKA used **MOD10A2-V5** (**maximum snow cover extent over eight-day period**) data during 2001-2011, to study snow cover upon our target area.

A threshold (50%) for cloud cover was set to reduce clouds noise over the scenes.

Batch data processing of **MODIS data** (through Python) was carried.

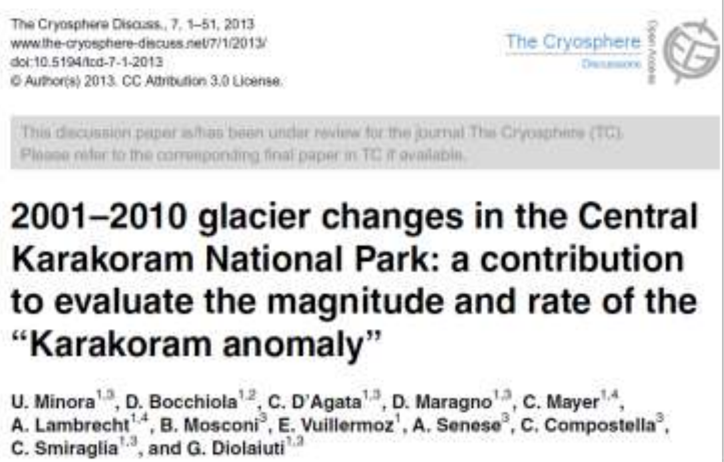
We investigated percentage of **snow cover changes per elevation belts** (e.g. Tahir et al. , 2011).

We evaluated a total of 37 images, for five selected dates (with most available data) during ablation season (from June 18th to September 30th).

Zone	Elevation range (m)	$AREA_{zone}$ (km^2)	Slope (km^2/year)	$Slope_{\%}$ (%/year)
A	1900-3300	845	0.09	2%
B	3301-4300	2803	2.35	0.6%
C	4301-8400	9551	14.86	0.2%
A_{TOT}/$Slope_{\%w}$()		**13200**	**17.31**	**0.25%**

Elevation zones for snow cover. *Slope* is value of slope from linear regression analysis upon average snow cover. *$Slope_{\%w}$* is slope weighted upon snow cover area.

Snow cover is substantially constant.

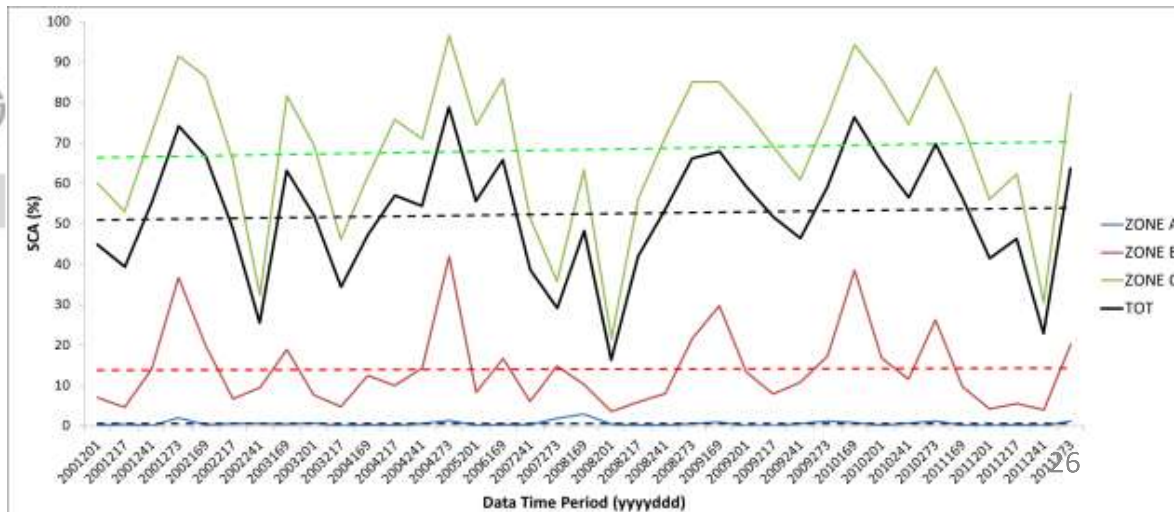

The Cryosphere Discuss., 7, 1–51, 2013
www.the-cryosphere-discuss.net/7/1/2013/
doi:10.5194/tcd-7-1-2013

The Cryosphere Discussions

This discussion paper is/has been under review for the journal The Cryosphere (TC). Please refer to the corresponding final paper in TC if available.

2001–2010 glacier changes in the Central Karakoram National Park: a contribution to evaluate the magnitude and rate of the "Karakoram anomaly"

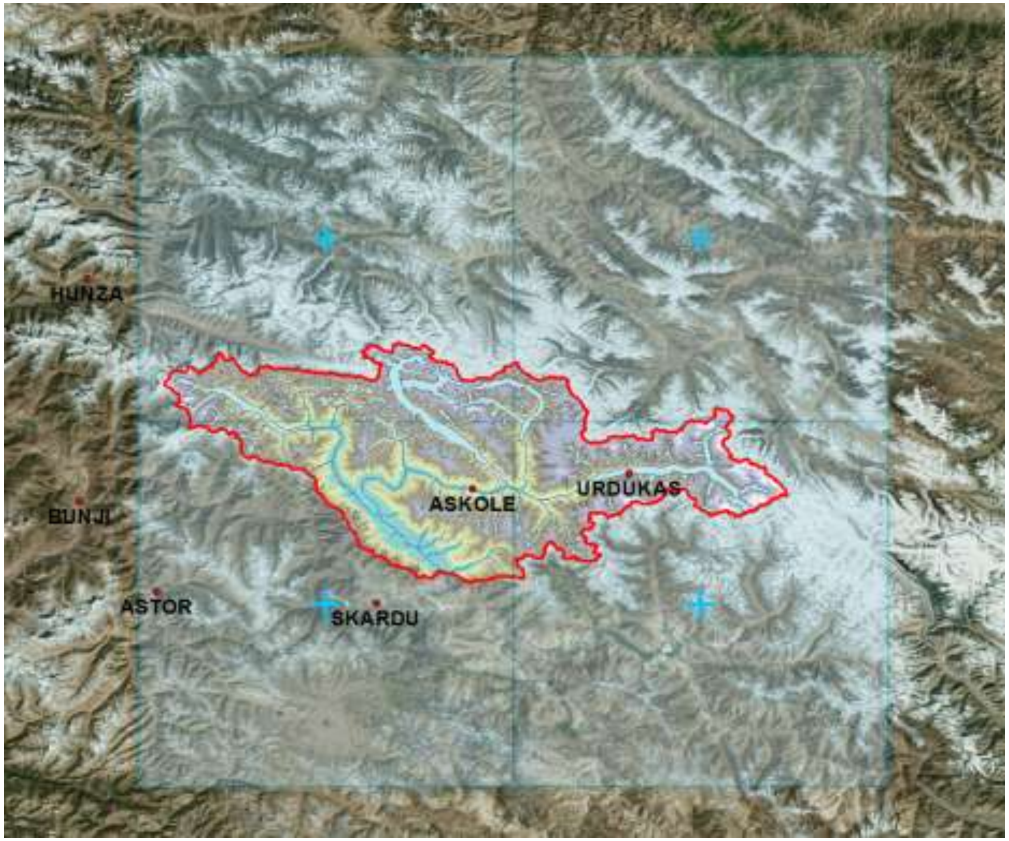
U. Minora[1,3], D. Bocchiola[1,2], C. D'Agata[1,3], D. Maragno[1,3], C. Mayer[1,4], A. Lambrecht[1,4], B. Mosconi[3], E. Vuillermoz[1], A. Senese[3], C. Compostella[3], C. Smiraglia[1,3], and G. Diolaiuti[1,3]

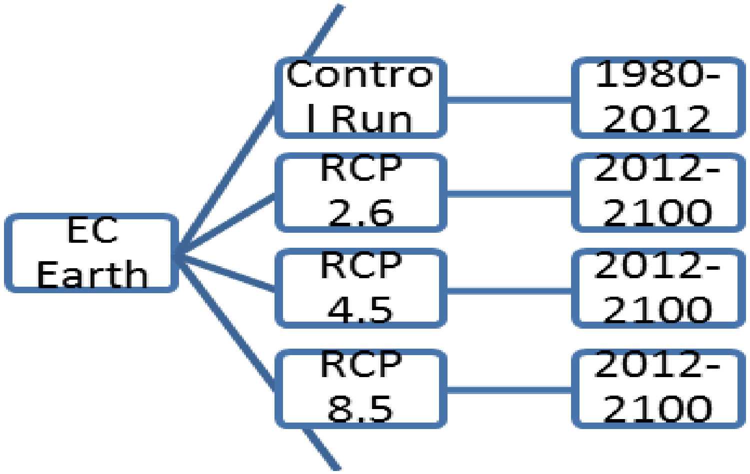


Hydrologic model

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)



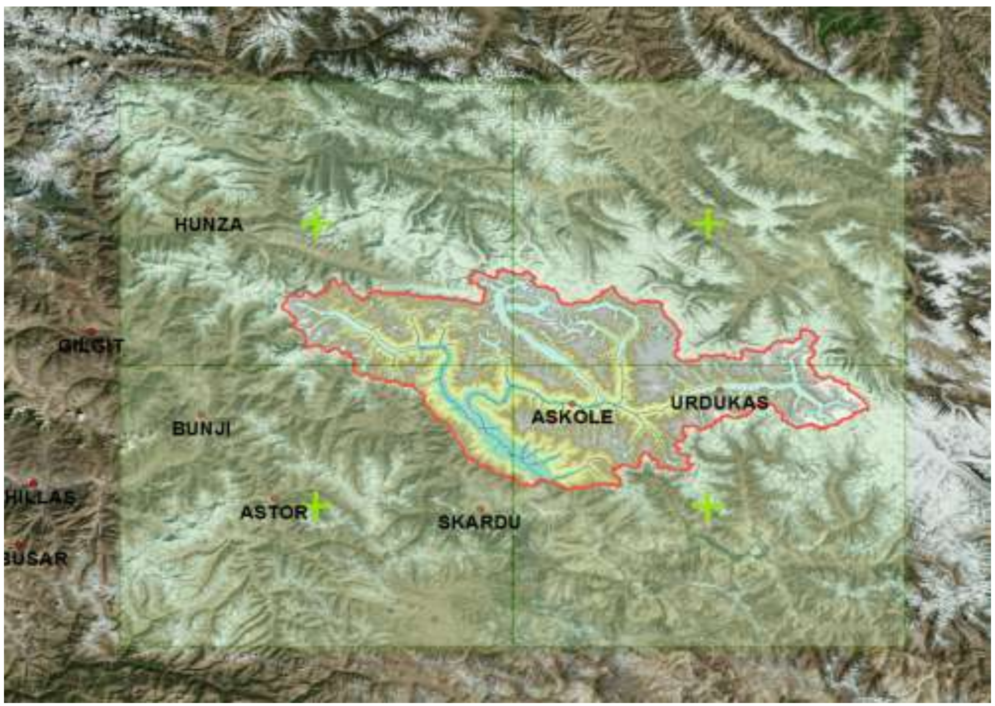


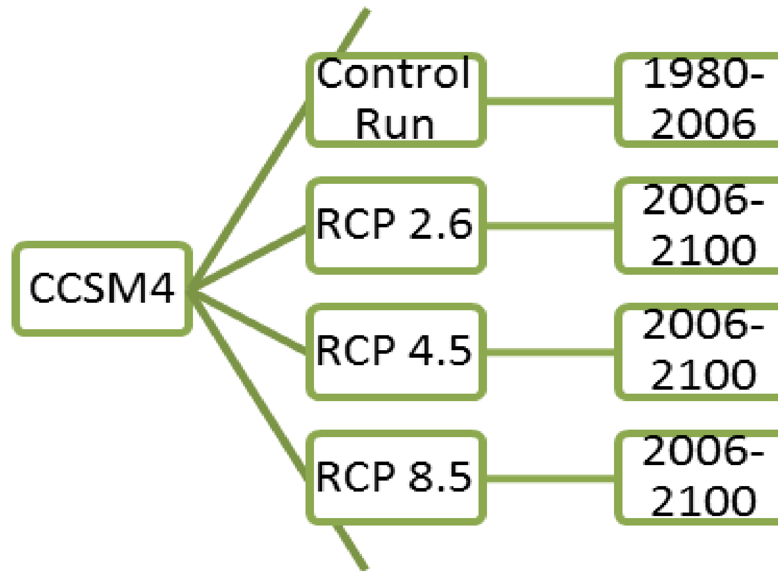
EC Earth - *EC-Earth consortium (10 EU countries)*

Hydrologic model

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)



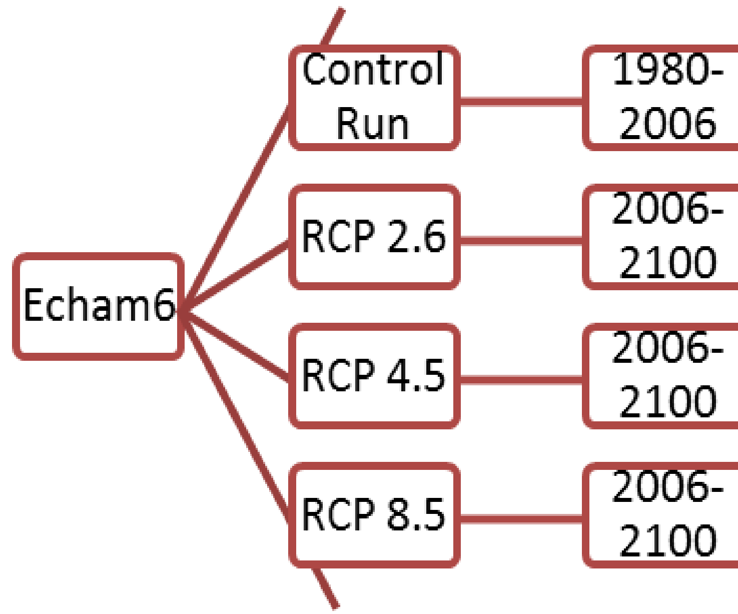


Community Climate System Model (CCSM) – *NCAR UCAR, USA*

Hydrologic model

GCMs for scenario simulations

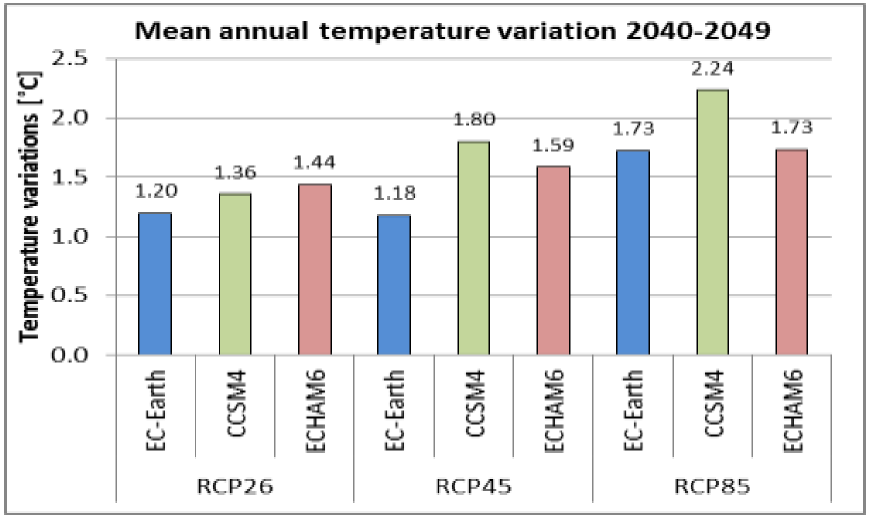
PAPRIKA used downscaled inputs from three different GCMs to project forward hydrology of the Shigar river over the investigated time horizon (until 2099)

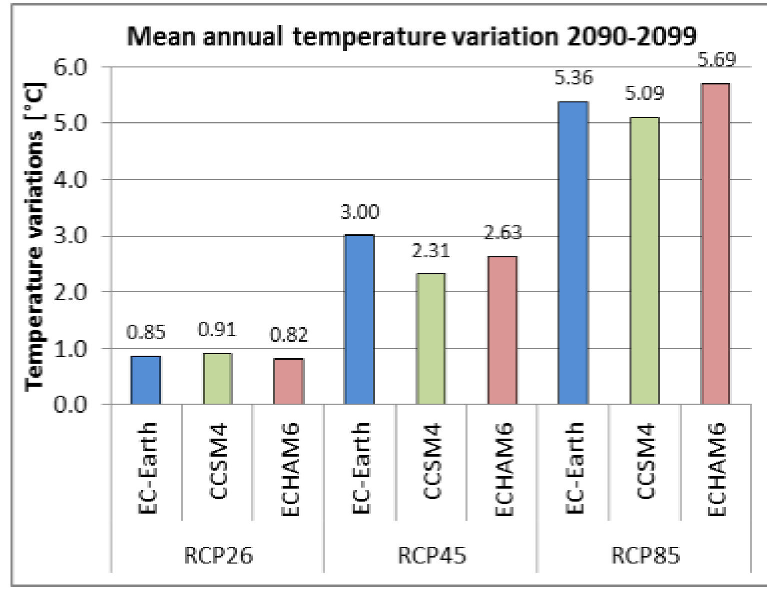


ECHAM - *Max Planck Institute for Meteorology, D*

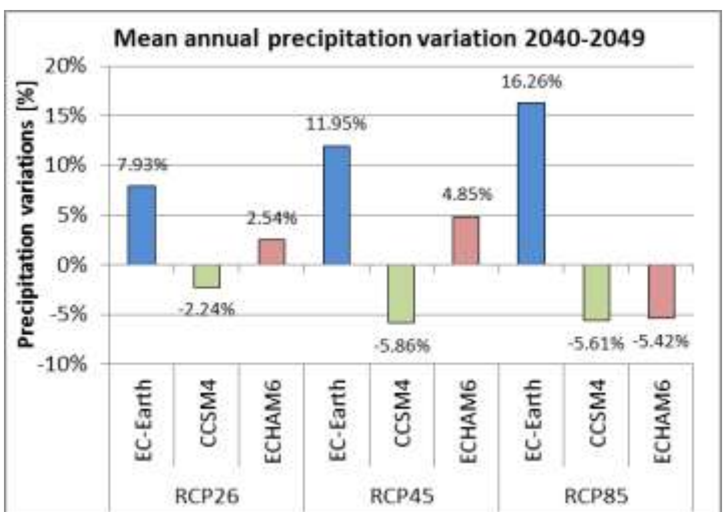
Hydrologic model

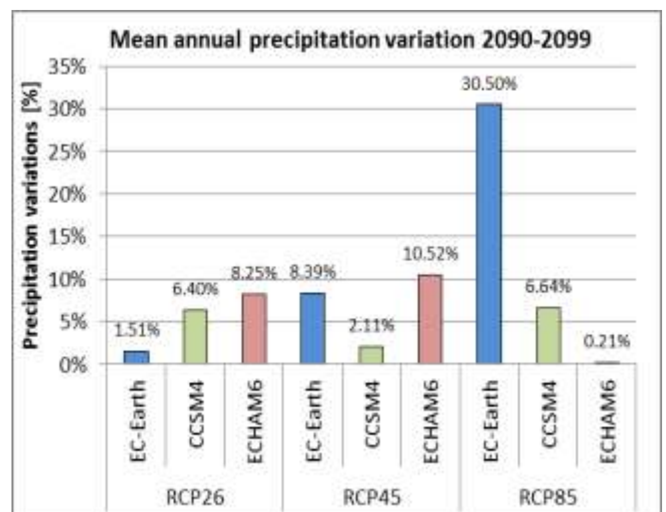
Temperature changes (yearly, Ref. 1980-2012)





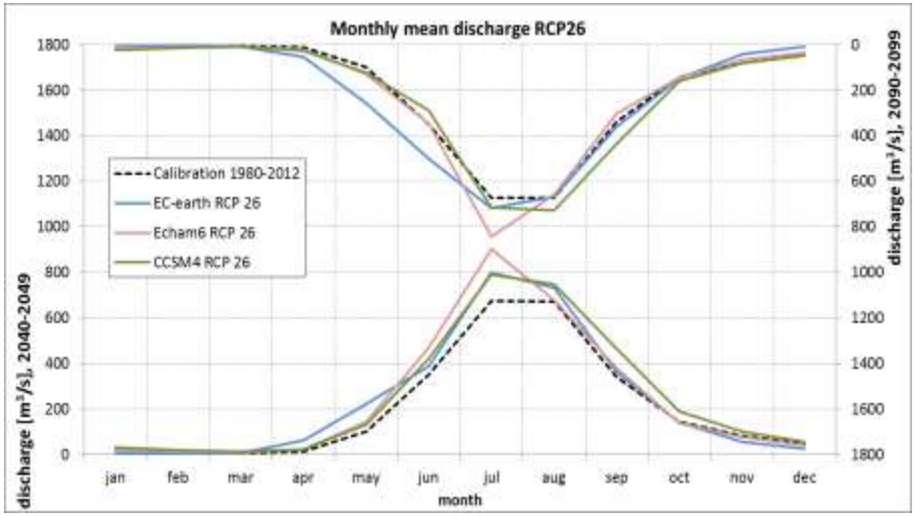
Precipitation changes (yearly, Ref. 1980-2012)

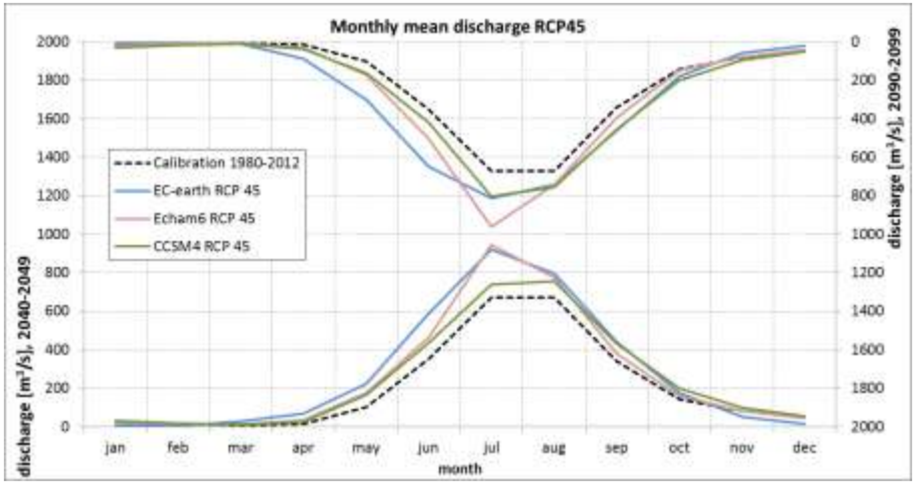


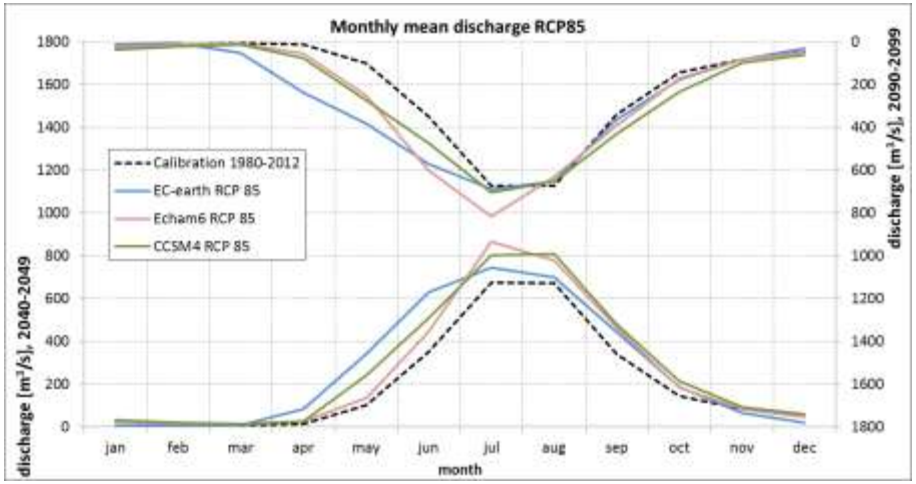


Hydrologic model

Hydrologic cycle (monthly)



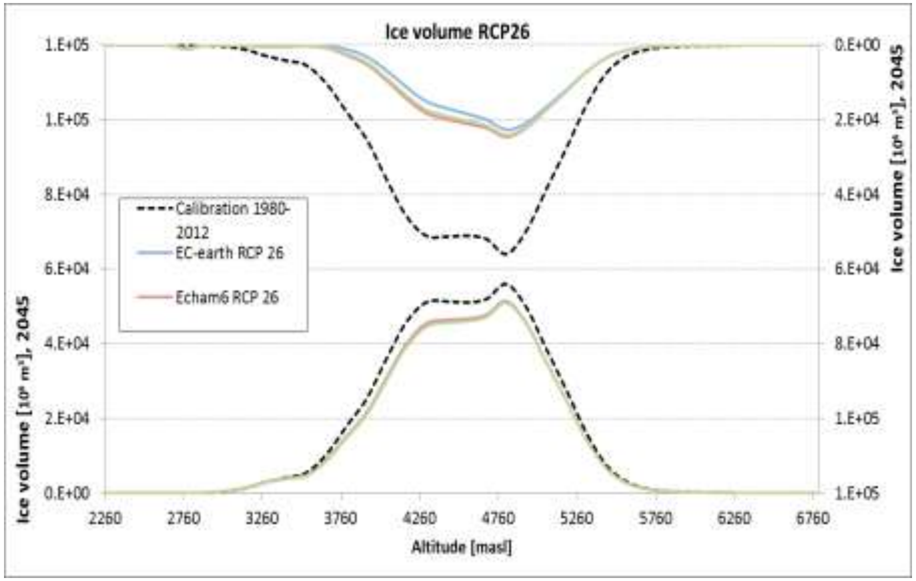


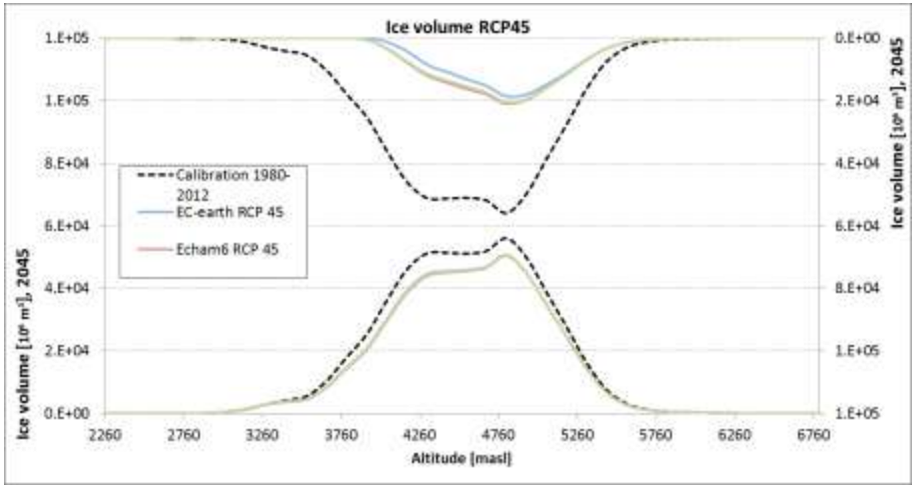


Streamflow will increase during the warm season, as sustained by ice melt, especially during July and August, but with a potential shift of high flows towards Spring months

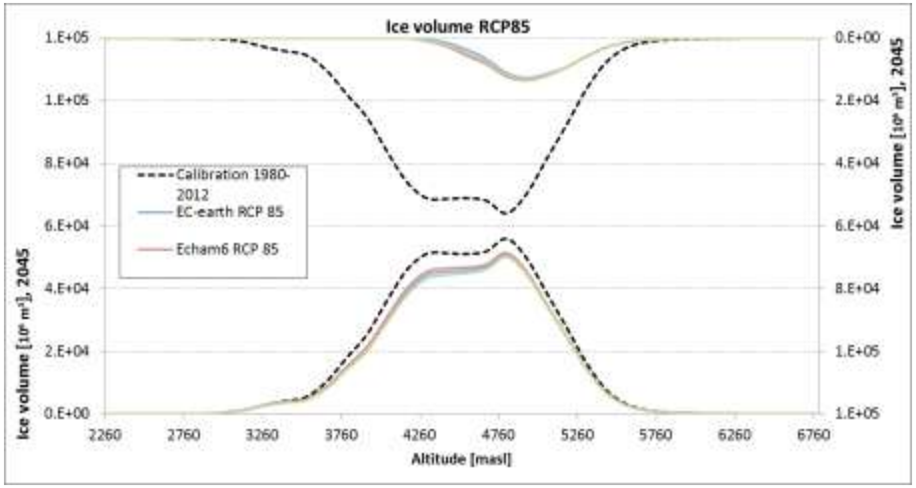
Hydrologic model

Expected available ice volume as per altitude bins





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



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

SEED project

Water

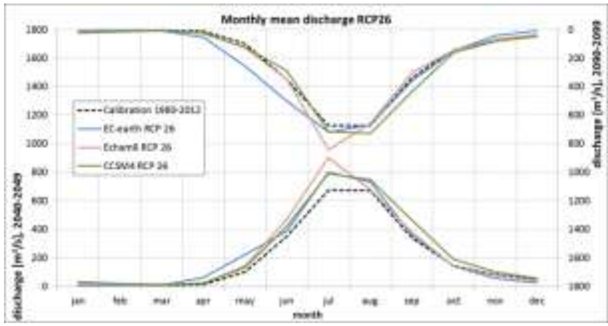
Within the framework of the **SEED** project, aimed to foster and support social, economic, and environmental development within the CKNP park, we developed studies explicitly devoted to establish procedures and protocols for assessment and management of water resources, specifically aimed to

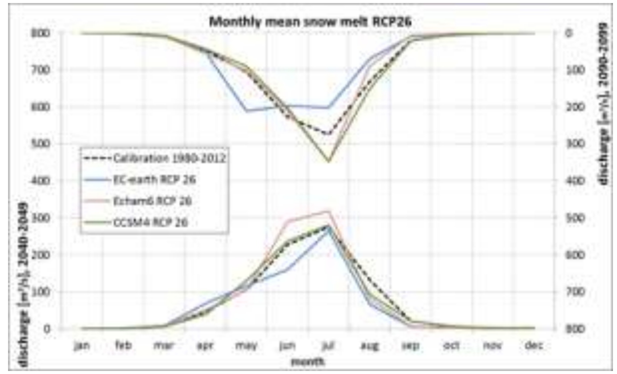
- Assess hydrological components and timing of water resources within the CKNP
- Propose a potential hydrological monitoring network for the CKNP area.
- Develop a proposed protocol for stream flow measurements
- Develop methodologies to model water resources availability, hydrological regimes, and floods under present, and perspective climate conditions.

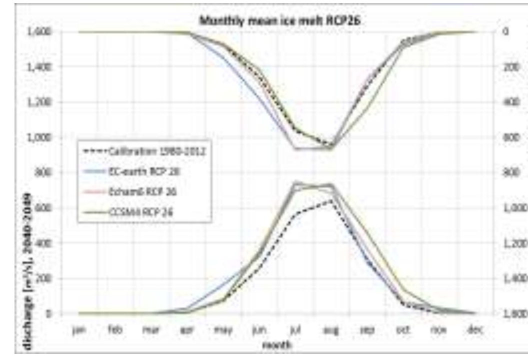
Hydrological components of water resources in Shigar river

We assessed the relative importance of the different components of the hydrological cycle, namely rainfall, snow melt, and ice melt within the Shigar river, under the present climate, and under prospective climate change, until 2099.

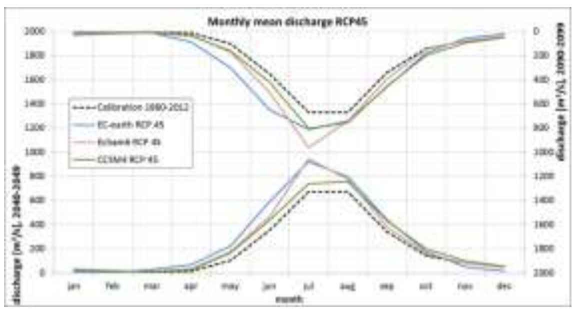
RCP 2.6

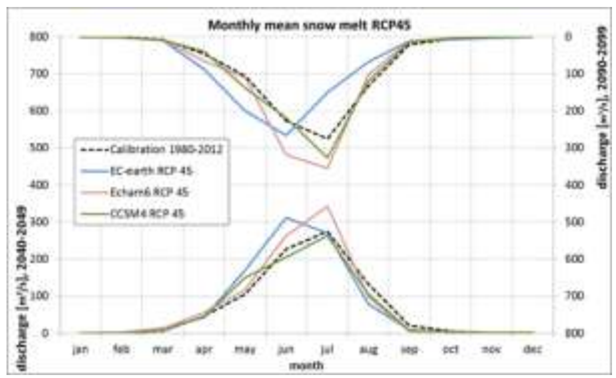


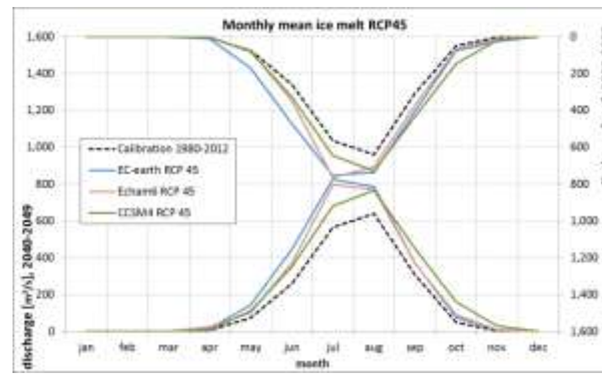




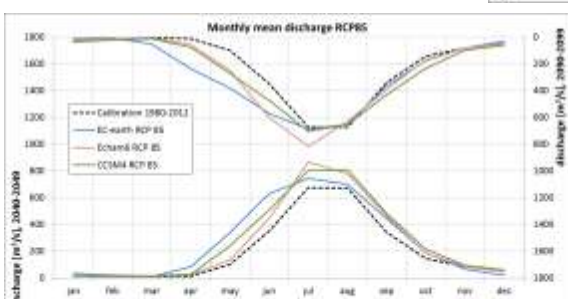
RCP 4.5

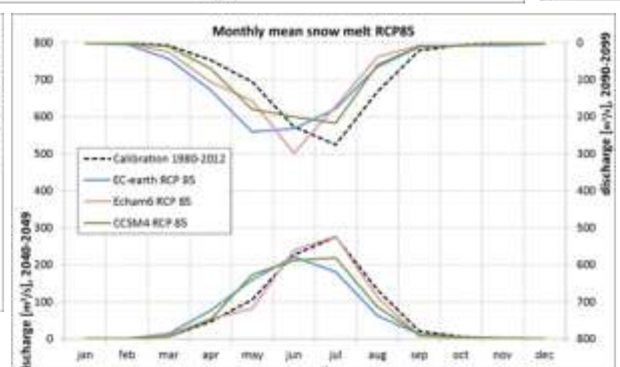


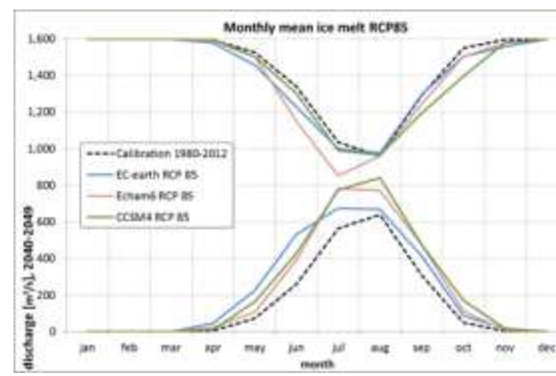




RCP 8.5







Conclusion (so far, 1)

Study of water resources in the cryosphere of Karakoram is a complex task, and it requires the combination of

i) **field studies under sometimes harsh landscape and environmental conditions,**

ii) **continuous monitoring through in situ stations, this including apparatus maintenance, and**

iii) **modeling of multifaceted environmental processes via nonstationary approaches**

High Summit LECCO 2013

Conclusion (so far, 2)

- **Notwithstanding so, research and development for water resources management, and flood hazard assessment, is tremendously important in the UIB**
- **Impending climate change may trigger relevant environmental changes, and adaptation measures are needed**
- **International cooperation has demonstrated tremendous potential, and it should continue hereforth**

SHARE paprika
Stations at High Altitude for Research on the Environment

seed
Social Economic Environmental Development

UN WATER
World Water Day 2013
International Year of Water Cooperation

Politecnico Milano

EvK2CNR