HKH Workshop, November 7 2014, Kathmandu

Precipitation, snow and atmospheric circulation in the Hindu-Kush Karakoram Himalaya: uncertainties and strengths in observations and global models

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Geographical and climatic characterization of the HKKH mountain region

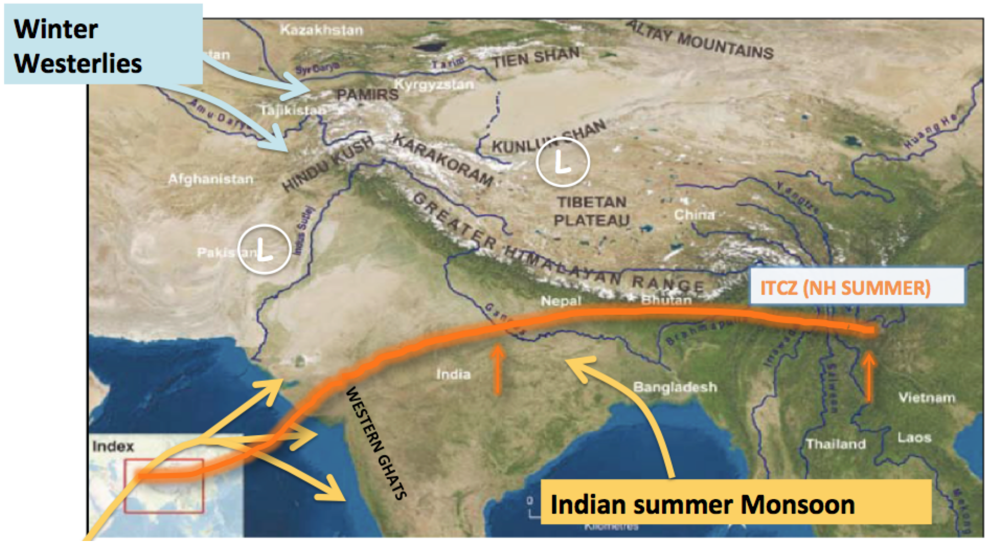
The third pole of the Earth, hosting the largest **reservoir of snow and ice** after the polar regions.

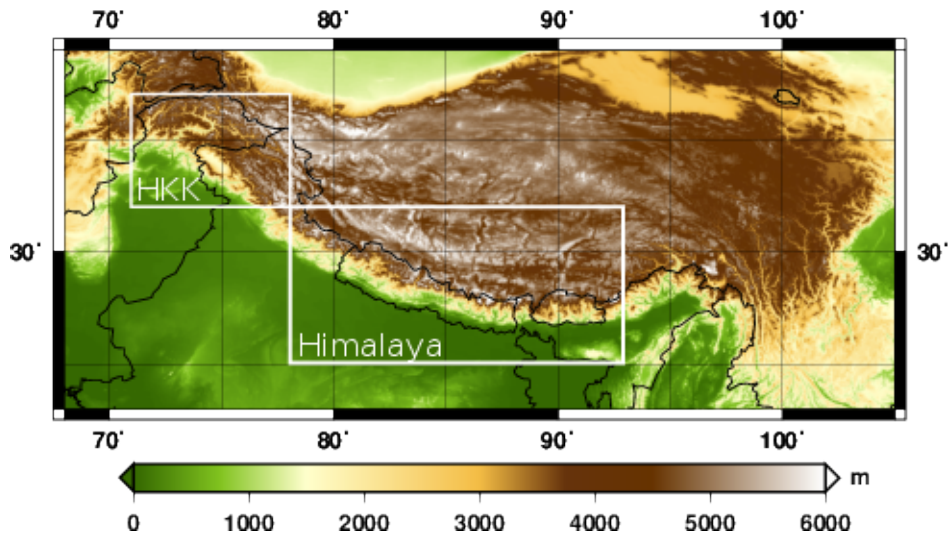
The **main river systems** in Asia originate from the HKKH mountains

Rivers are fed by snow/ice melt and by orographic precipitation brought by two main atmospheric systems:
- **Western Weather Patterns (winter-early spring)**
- **Indian Monsoon (summer)**

Changes in precipitation and snowpack distribution impact water availability.

Our understanding of precipitation and snowpack dynamics in the HKKH region is still incomplete owing also to uncertainties in observations and model simulations.





Precipitation in the HKKH region: a view from the observations and GCM simulations

JOURNAL OF GEOPHYSICAL RESEARCH
Atmospheres
AN AGU JOURNAL

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Regular Article

Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios

E. Palazzi, J. von Hardenberg and A. Provenzale

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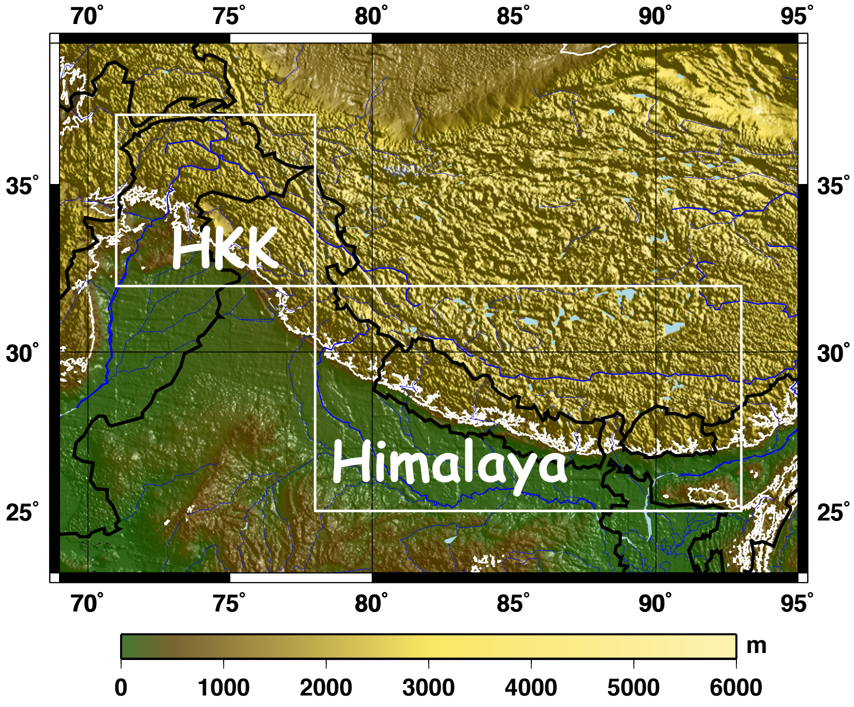
Precipitation in the Karakoram-Himalaya: a CMIP5 view

Elisa Palazzi · Jost von Hardenberg · Silvia Terzago · Antonello Provenzale



We consider only the data and model outputs from pixels/grid points with mean elevation higher than 1000 m above mean sea level.

Spatial averages over the two boxes of

- ✧ Gridded precipitation data + reanalyses
- ✧ Data from GCMs

- ✧ Annual cycle climatology
- ✧ Long-term trends
- ✧ Changes

a. Precipitation

Data and approach

1

DATASET	Spatial domain	Temporal domain	Spatial resolution	Temporal resolution
TRMM 3B42	50°S-50°N	1998-2010	0.25°x0.25°	3-hr
GPCP	Global	1979-2010	2.5°x2.5°	Monthly
APHRODITE APHRO_V1003R1	60°E-150°E 15°S-55°S	1951-2007	0.25°x0.25°	Daily
GPCC V5	Land	1901-2009	0.5°x0.5°	Monthly
CRU TS3.01.01	Land	1901-2009	0.5°x0.5°	Monthly
ERA-Interim	Global	1979-2011	0.75°x0.75°	Daily
EC-Earth GCM	Global	1850-2005 + scenarios	1.125°x1.125°	Daily

DATASET	Advantages	Drawbacks
Satellite	Spatially-complete coverage of precipitation estimates	- Not yet suitable for climatological studies - Snow
Gridded datasets	- Long temporal coverage - Advantages of gridding	- Uncertainties from poor spatial coverage and high sparseness - Short averaging time scales - Snow
Reanalysis data	- Account for total precipitation - Global and continuous	- Climate trends are uncertains

Multiannual mean (1998-2007) of JJAS precipitation

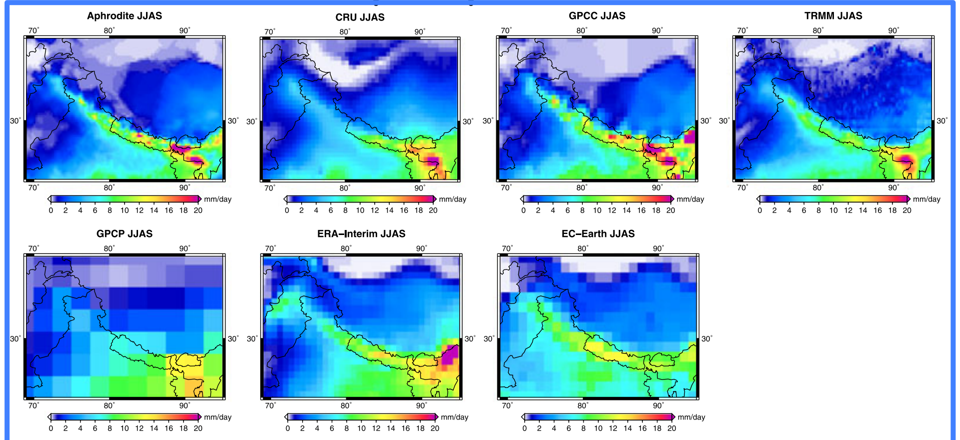
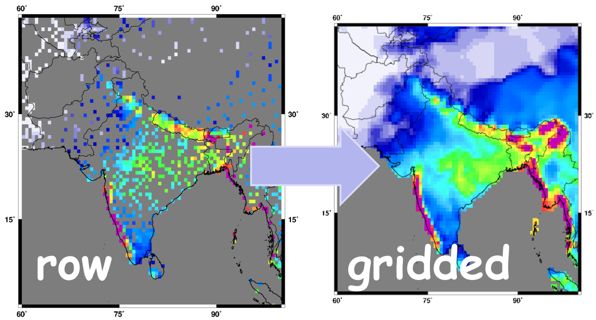


Figure 2. Multiannual mean (1998–2007) of summer (JJAS) precipitation over the region between 69°E–95°E and 23°N–39°N from the APHRODITE, CRU, GPCC, TRMM, GPCP, ERA-Interim, and EC-Earth model data sets.

GPCC



- How the various data sets represent the properties of precipitation in the two regions in terms of precipitation amounts, seasonality, and trends.

- We do not try to define a ground "truth" for precipitation in the two sub-regions, but use a multiprobe source data.

a. Precipitation

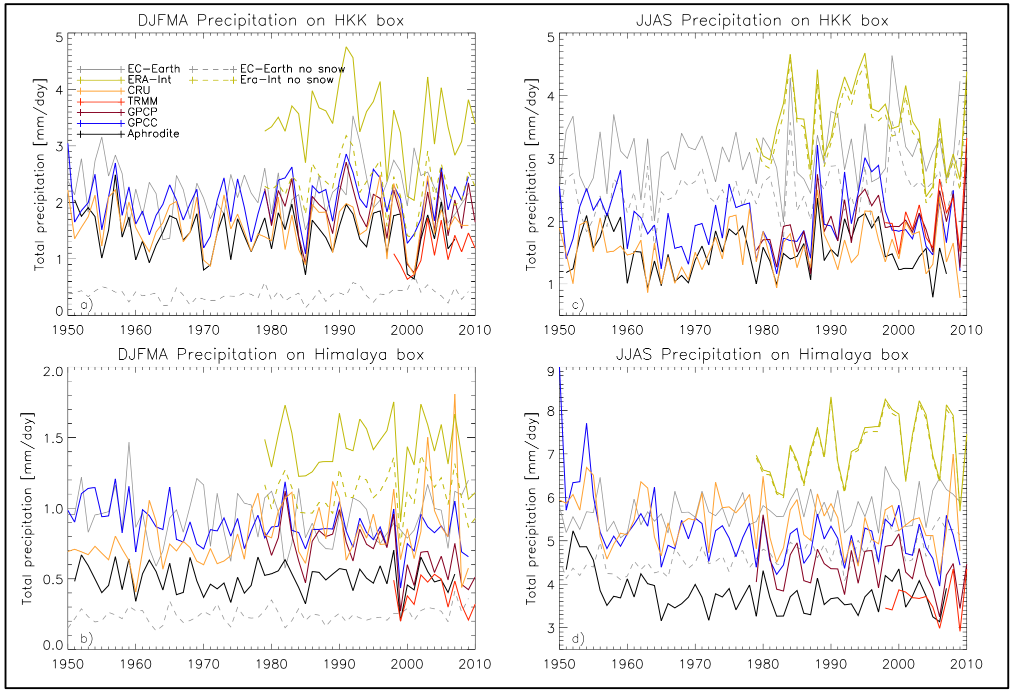
Annual cycle and trends

1

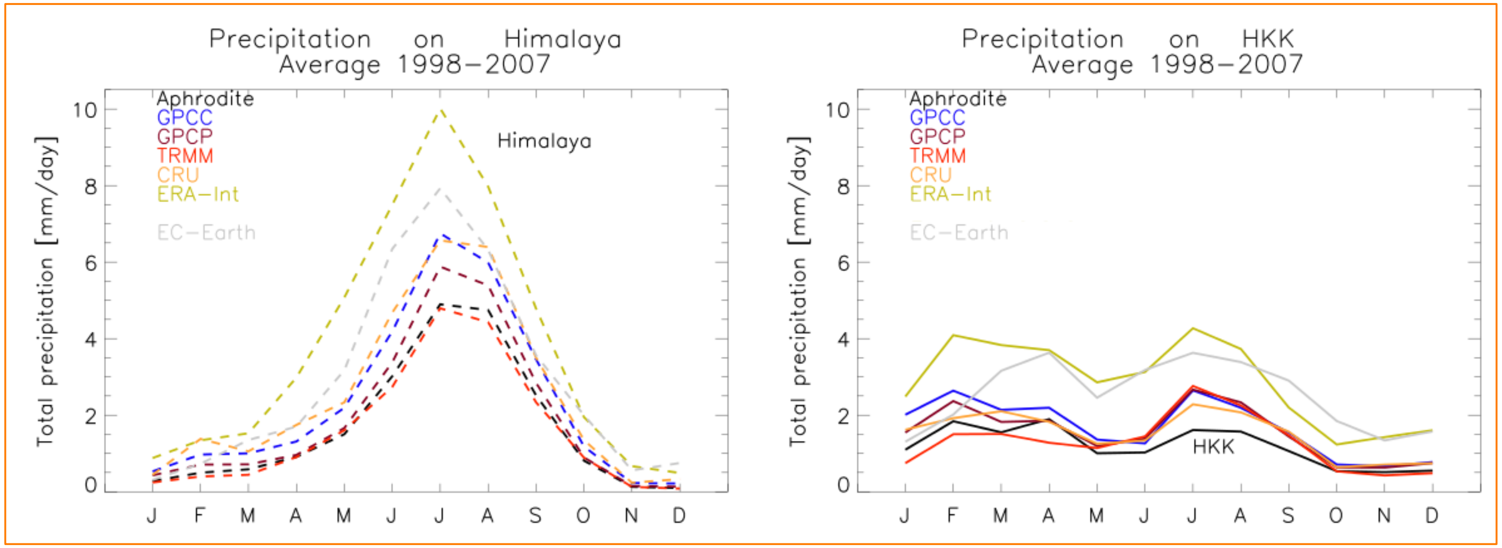
Seasonal trends (mm/day/decade)

		Himalaya		HKK	
	DATASET	JJAS	DJFMA	JJAS	DJFMA
1951-2007	APHRODITE	-0.10	0.0	0.0	-0.03
1950-2009	CRU	-0.08	0.05	0.02	-0.01
1950-2009	GPCC	-0.21	-0.04	0.0	0.02
1998-2010	TRMM	0.15	-0.06	0.57	0.41
1979-2010	GPCP	-0.12	-0.10	0.17	-0.07
1979-2010	ERA-Interim (no snow)	0.27 (0.27)	-0.02 (0.0)	-0.11 (-0.11)	-0.12 (-0.07)
1950-2009	EC-Earth (no snow)	0.08 (0.14)	-0.01 (0.01)	0.05 (0.07)	0.0 (0.01)

Seasonal time series



Precipitation Annual cycle (1998-2007)



Himalaya: unimodal distribution

HKK: bimodal distribution

Reanalysis and GCM data overestimate total precipitation with respect to the obs.

a. Precipitation

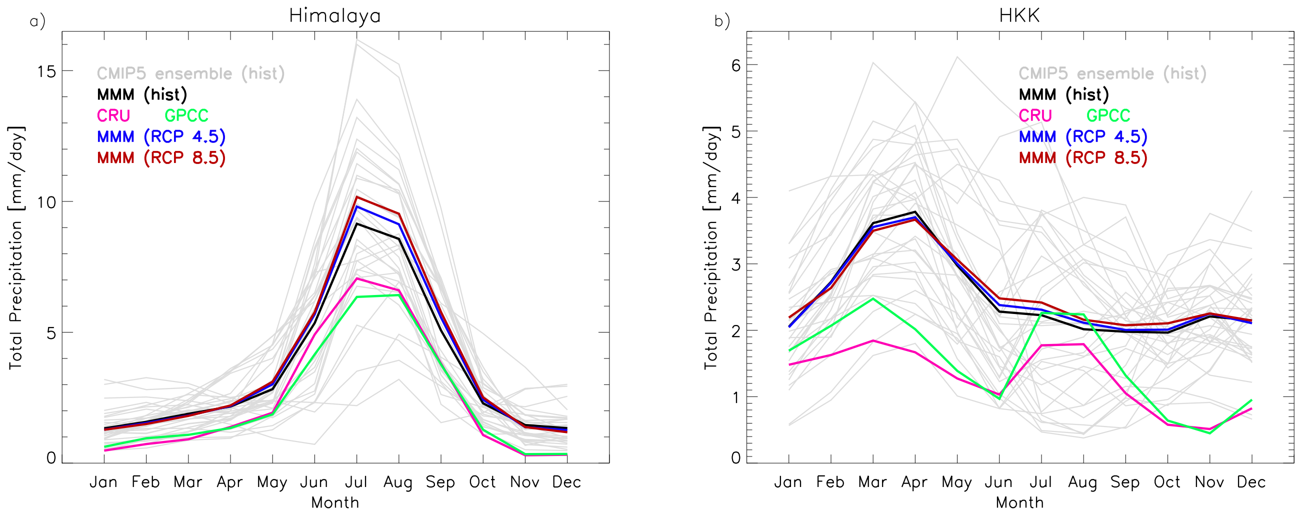
Annual cycle: CMIP5 GCMs

32 CMIP5 Global Climate Models

2

Table 1 The CMIP5 models used in this study

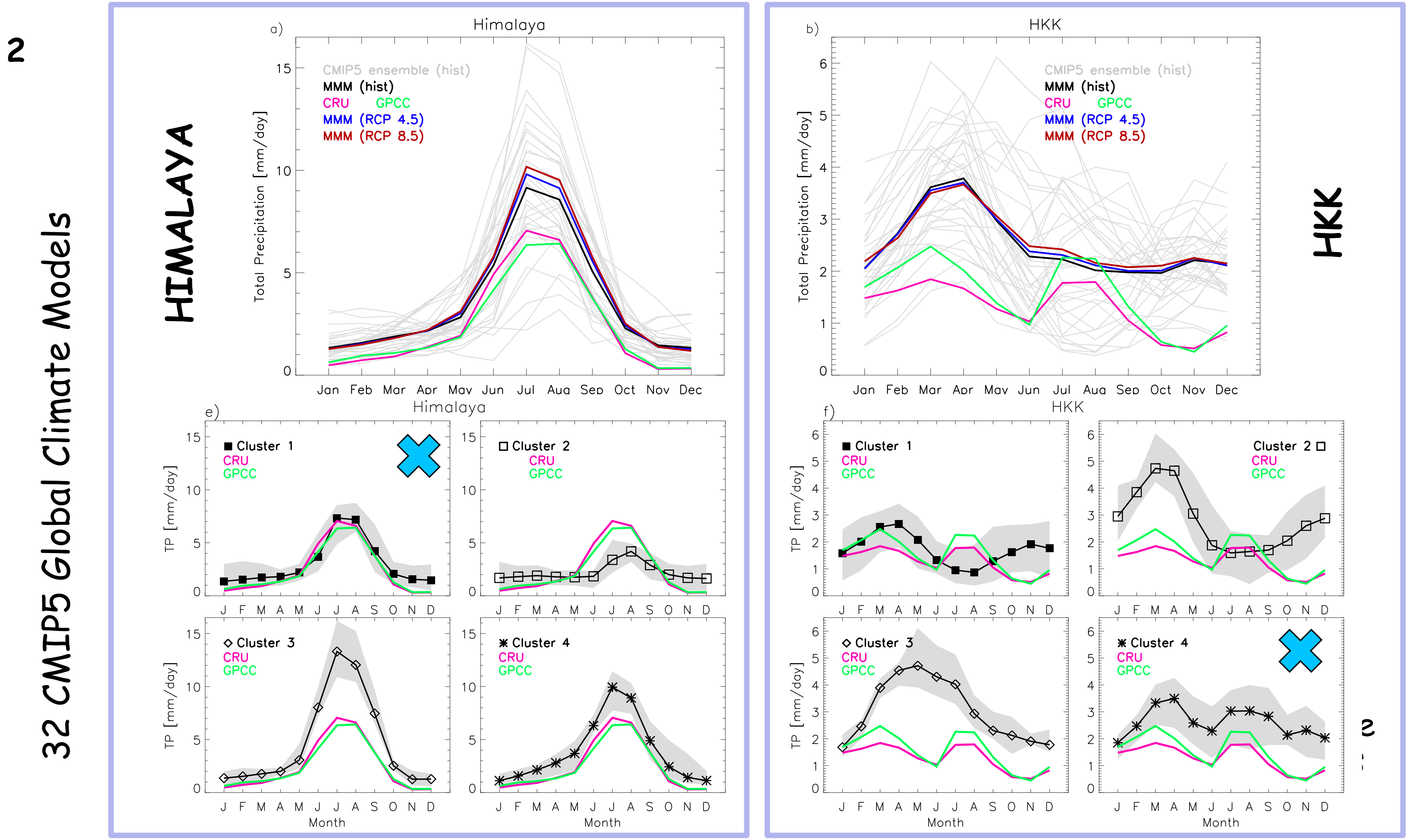
Model ID	Resolution Lon × Lat° Lev
bcc-csm1-1-m	1.125 × 1.125L26 (T106)
bcc-csm1-1	2.8125 × 2.8125L26 (T42)
CCSM4	1.25 × 0.9L27 (T63)
CESM1-BGC	1.25 × 0.9L27
*CESM1-CAM5	1.25 × 0.9L27
EC-Earth	1.125 × 1.125L62 (T159)
FIO-ESM	2.8125 × 2.8125L26 (T42)
GFDL-ESM2G	2.5 × 2L24 (M45)
GFDL-ESM2M	2.5 × 2L24 (M45)
MPI-ESM-LR	1.875 × 1.875L47 (T63)
MPI-ESM-MR	1.875 × 1.875L95 (T63)
*CanESM2	2.8125 × 2.8125L35 (T63)
CMCC-CMS	1.875 × 1.875L95 (T63)
CNRM-CM5	1.40625 × 1.40625L31 (T127
*CSIRO-Mk3-6-0	1.875 × 1.875L18 (T63)
*GFDL-CM3	2.5 × 2L48 (C48)
INM-CM4	2 × 1.5L21
IPSL-CM5A-LR	3.75 × 1.89L39
IPSL-CM5A-MR	2.5 × 1.2587L39
IPSL-CM5B-LR	3.75 × 1.9L39
*MRI-CGCM3	1.125 × 1.125L48 (T159)
CMCC-CM	0.75 × 0.75L31 (T159)
FGOALS-g2	2.8125 × 2.8125L26
*HadGEM2-AO	1.875 × 1.24L60
*ACCESS1-0	1.875 × 1.25L38 (N96)
*ACCESS1-3	1.875 × 1.25L38
*HadGEM2-CC	1.875 × 1.24L60 (N96)
*HadGEM2-ES	1.875 × 1.24L38 (N96)
*MIROC5	1.40625 × 1.40625L40 (T85)
*MIROC-ESM	2.8125 × 2.8125L80 (T42)
*NorESM1-M	2.5 × 1.9L26 (F19)
*NorESM1-ME	2.5 × 1.9L26



- Two reference long data sets evaluated in the period 1901-2005: CRU and GPCC
- Model overestimation (many individual GCMs as well as the MMM) with respect to CRU and GPCC
- Spread (multimodel standard deviation/multimodel mean): maximum in summer in HKK
- The models providing a similar representation of the precipitation annual cycle in the sub-regions have been grouped by using a hierarchical clustering analysis

a. Precipitation Annual cycle: CMIP5 GCMs

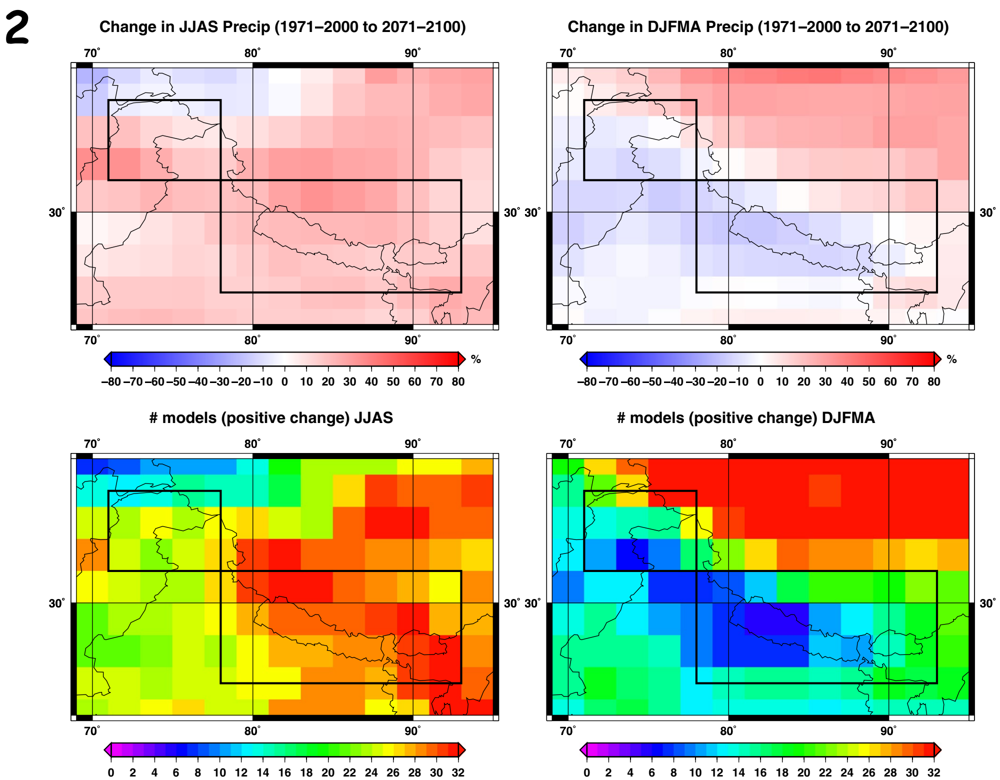
2



No single model or group of models emerges as that providing the best results in terms of precipitation annual cycle (and for the other statistics considered), and in both sub-regions.

a. Precipitation

Future changes and trends: CMIP5 GCMs



Maps of Changes
(future RCP8.5-present)

- Wetter future conditions in Himalaya in summer
- Wetter future condition in HKK in summer (RCP8.5)
- Drier future condition in HKK in winter (RCP8.5)

		Himalaya			HKK		
		Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
JJAS	CRU	**-0.416**			0.097		
	GPCC	**-1.445**			0.101		
	MMM	-0.076	**1.027**	**1.860**	**0.094**	0.054	**0.186**
	Best Cluster	-0.068	**0.500**	**1.357**	0.068	0.002	0.116
DJFMA	CRU	0.033			**0.332**		
	GPCC	**-0.355**			0.002		
	MMM	-0.011	0.016	-0.051	**-0.073**	-0.006	**-0.097**
	Best Cluster	-0.021	0.071	-0.25	-0.163	-0.025	**-0.327**

Trends

(mm/day/century)

b. Snow pack

Data & approach

Journal of Hydrometeorology 2014 ; e-View
doi: http://dx.doi.org/10.1175/JHM-D-13-0196.1

Snowpack changes in the Hindu-Kush Karakoram Himalaya from CMIP5 Global Climate Models

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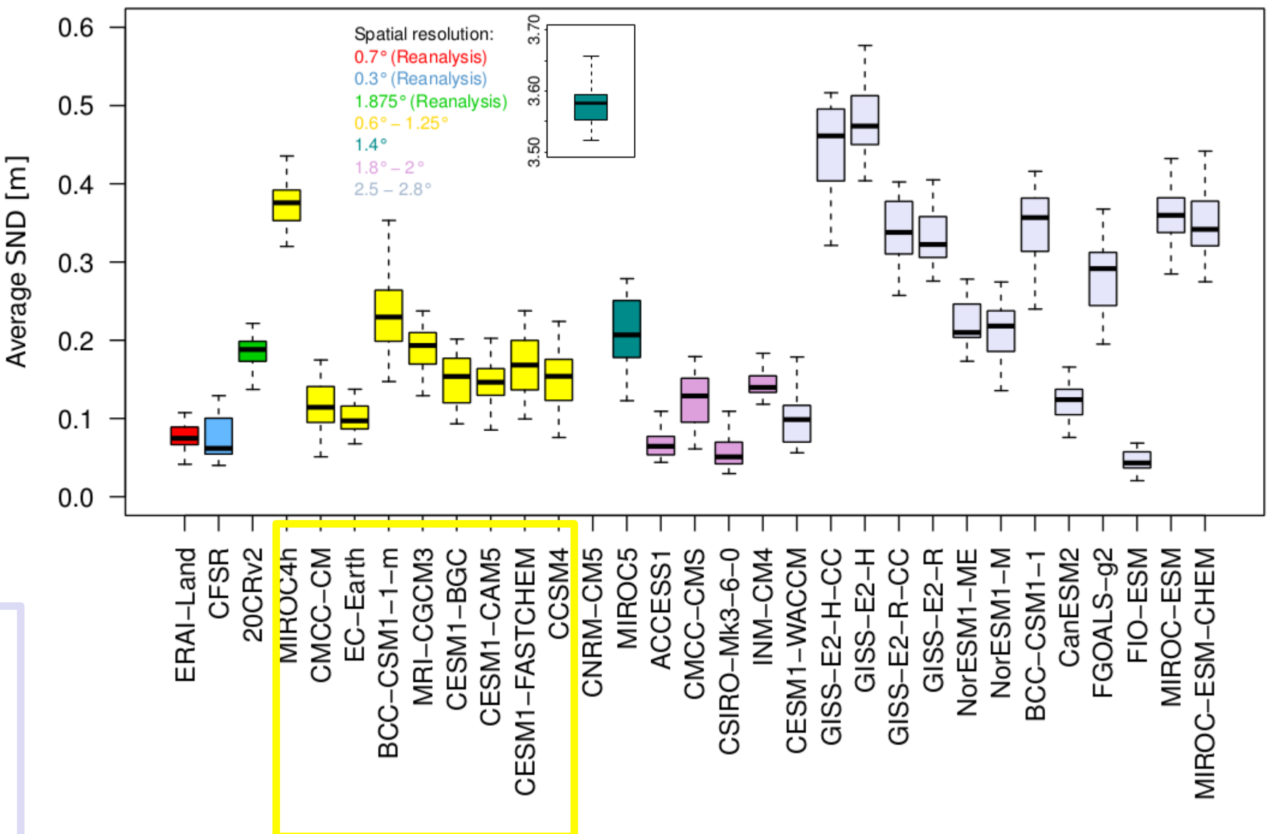
Comparison between CMIP5 GCMs and Reanalyses (SNOW DEPTH, SNOW WATER EQUIVALENT)

- **ERA-Interim/Land (0.7°)**
- **CFSR (0.3°)**
- **20CR V2 (1.8°)**

GCMs with resolution up to 1.25° agree better with each other, with reanalyses and with the orographic features

GCMs with resolution > 2.5° generally overestimate snow depth with respect to reanalyses

Average DJFMA snow depth in HKKH above 1000 m a.s.l. (1980–2005)



b. Snow pack

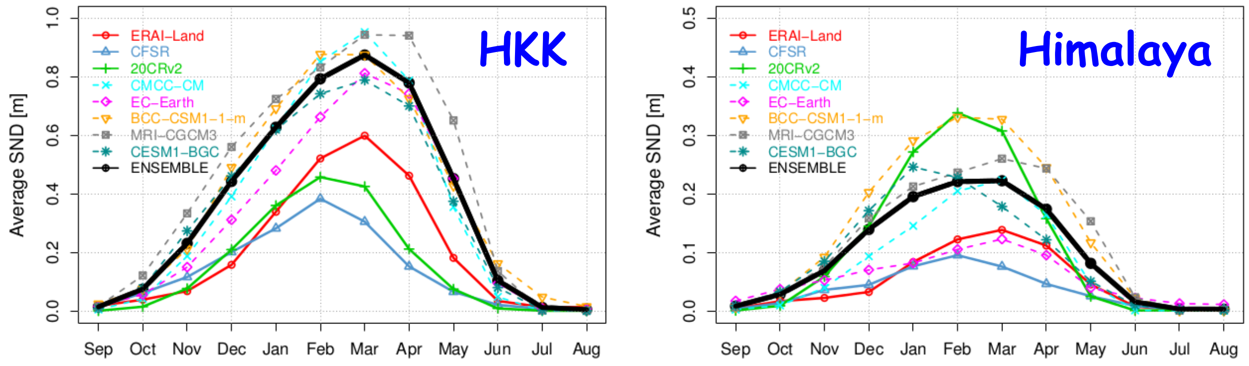
Snow depth Annual cycle & changes

Seasonal cycle: unimodal regime, maximum in Feb/Mar

HKK
High resolution GCMs overestimate snow depth with respect to reanalyses

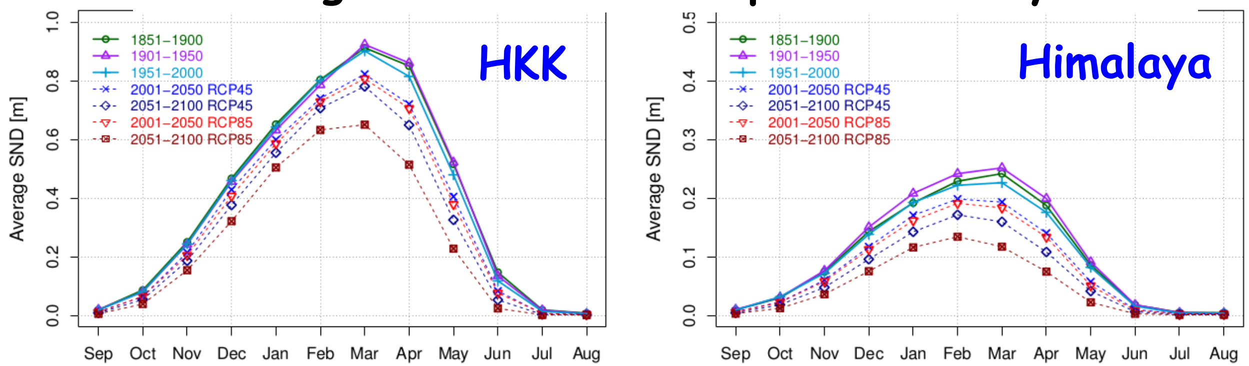
Himalaya
GCM ensemble mean lies in the (large) range of variability of reanalysis

Snow Depth Annual Cycle (1980-2005)



Expected changes in annual cycle

Changes in the Snow Depth Annual Cycle

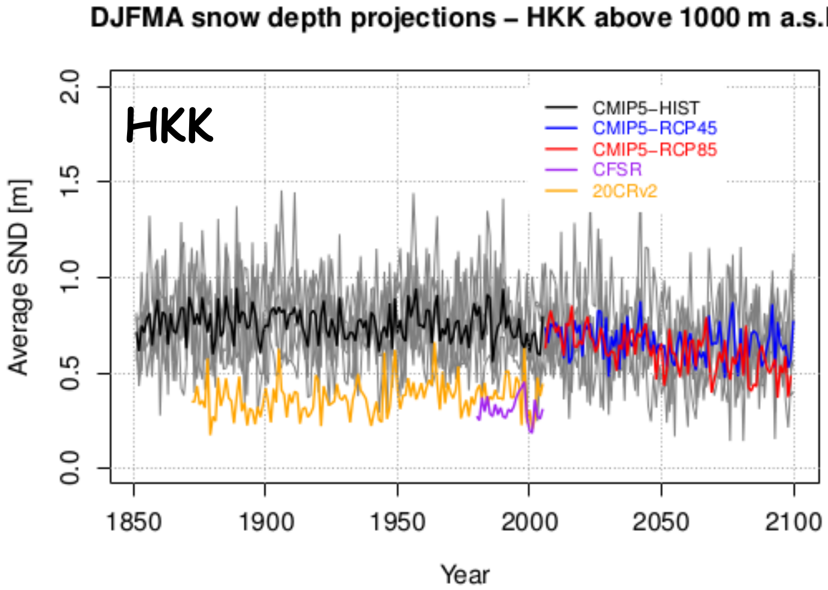


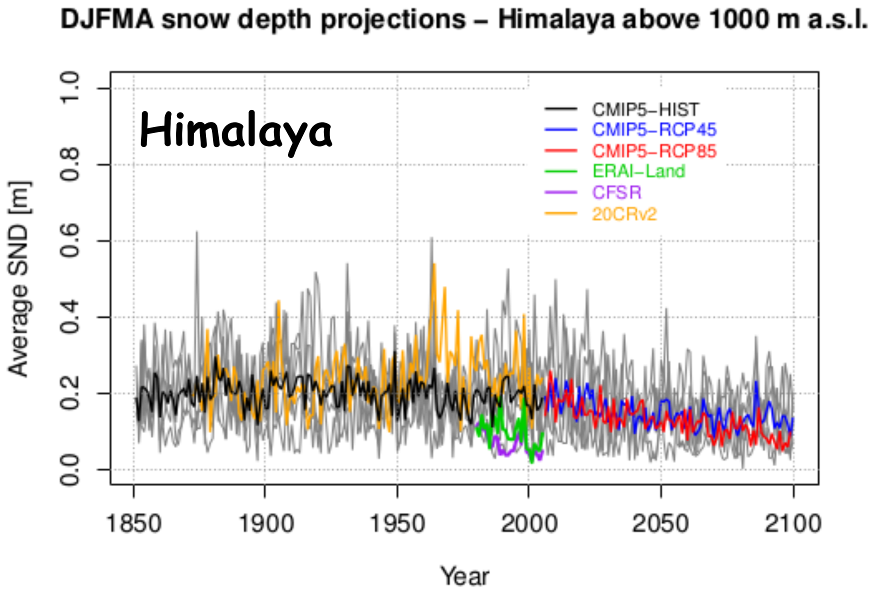
Strong reduction in snow depth expected for the end of the 21st century in both regions, in particular in the RCP85 scenario.

Anticipation of the snow depth maximum from March to February in Himalaya → earlier melting implies anticipation of the river discharge peak & water availability in downstream areas

b. Snow pack Snow depth trends: present and future

DJFMA TIME SERIES





DJFMA TREND

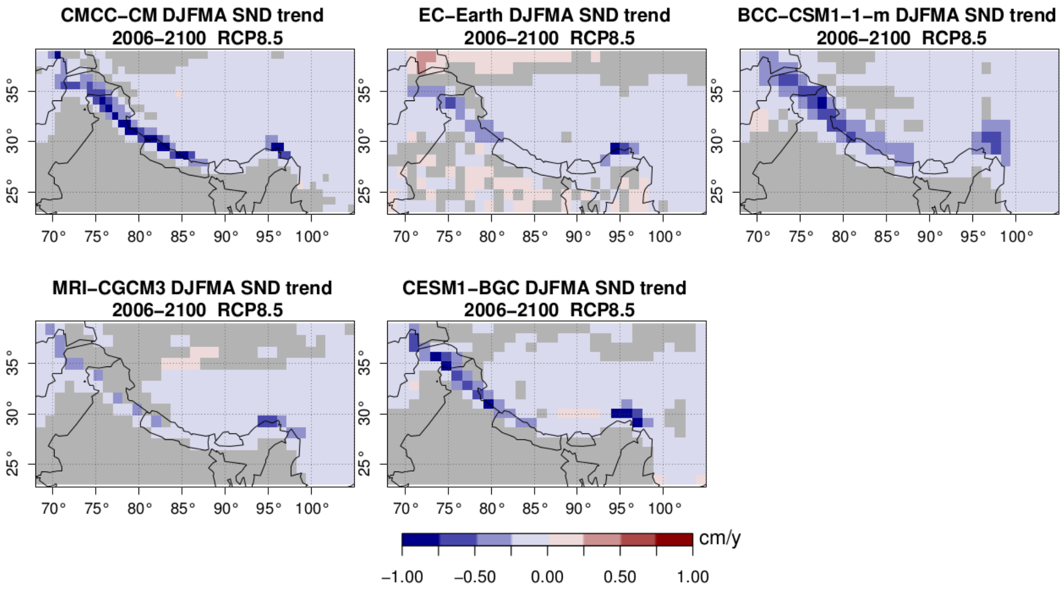


FIG. 8. Spatial distribution of the winter (DJFMA) trends of snow depth, estimated over the projection period 2006-2100 (RCP8.5 scenario) and significant at the 95% confidence level.

REDUCTION in the SPATIAL AVERAGE of SNOW DEPTH

	Snow depth reduction rate [%/century]	
	HKK	Himalaya
Historical	-6	-8
RCP45	-17	-25
RCP85	-39	-50

Linked with increases in winter Temperature

c. Circulation

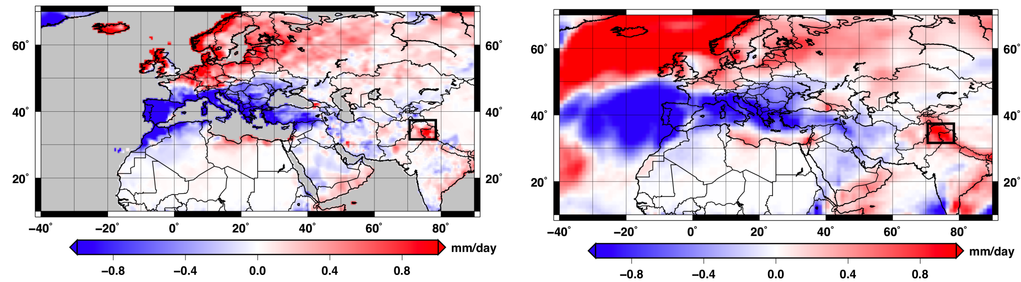
NAO, WWP, HKK precipitation

- **Winter precipitation in the Karakoram is associated with WWP**

- **The dynamics of WWP is affected by the NAO** (larger precipitation is typically recorded during the positive NAO phase)

Difference of precipitation between the positive and the negative NAO phase

GPCC (1958-2002) **ERA40 (1958-2002)**



APHRODITE (1951-2007)
Product: APHRO_MA(Monsoon Asia)_V1101
Temporal resolution: daily. Spatial resolution: 0.25°x0.25°
Coverage: 60°E-150°E,15°S-55°N

GPCC (1901-2010)
Product: v6. Temporal resolution: monthly
Spatial resolution: 0.5°x0.5°. Coverage: global

CRU (1901-2012)
Product: TS 3.21. Temporal resolution: monthly
Spatial resolution: 0.5°x0.5°. Coverage: global

- Investigate the **relationship between the NAO and winter precipitation** in the HKK using a multi-dataset approach

- Explore the **mechanisms** by which the NAO regulates WWPs and precipitation in the HKK

- Study the **multi-decadal variability** of the NAO-precipitation relationship in the last century.

ERA40 (Sept 1957-Aug 2002)
Temporal resolution: daily
Spatial resolution: 1.125°x1.125°
Coverage: global

20CR (1871-present)
Product: version 2
Temporal resolution: monthly
Spatial resolution: 1.125°x1.125°
Coverage: global

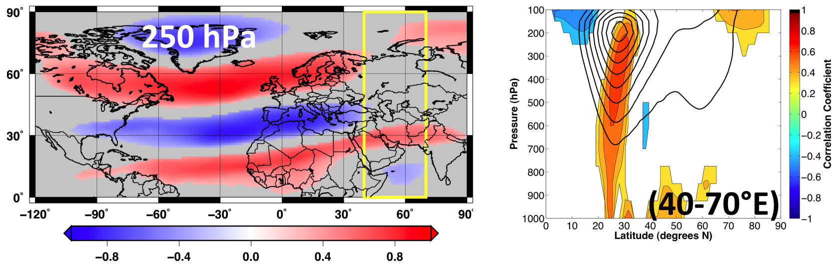
c. Circulation Mechanism

Positive NAO phase

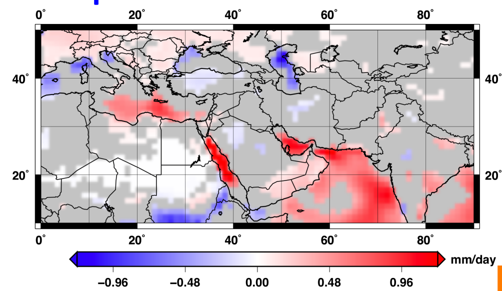
Intensification of westerlies in the region of the **Middle East Jet Stream (MEJS)**

Enhanced evaporation from the reservoirs (Persian Gulf, Red sea, northern Arabian sea) due to higher surface wind speed

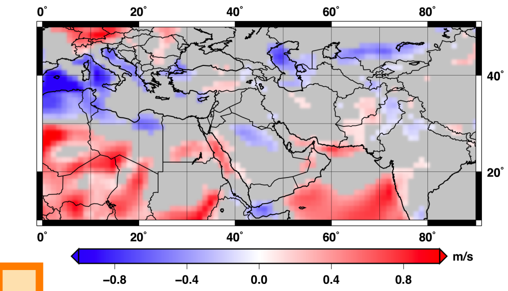
Correlation NAO – Zonal Wind



Evaporation: POS - NEG NAO



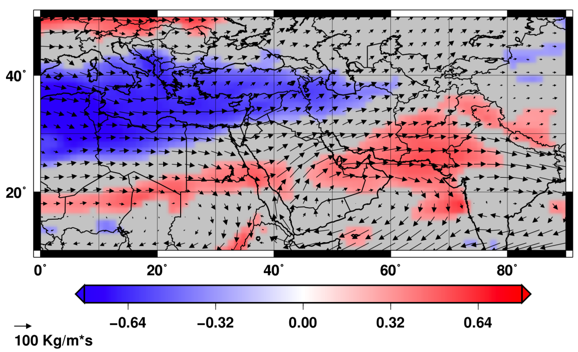
10m Wind Speed: POS - NEG NAO



Stronger Jet **intensifies WWPs** + **Increased humidity from evaporation**

Enhanced and faster transport of humidity towards the HKK

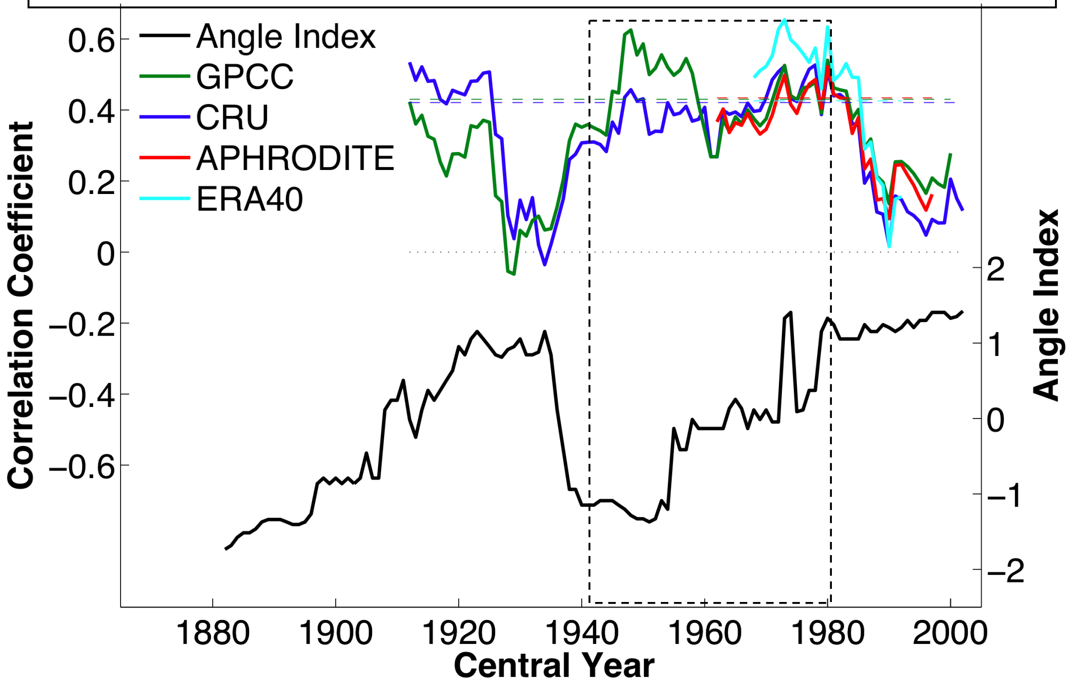
Correlation NAO – Moisture Transport



c. Circulation NAO-precip. relationship

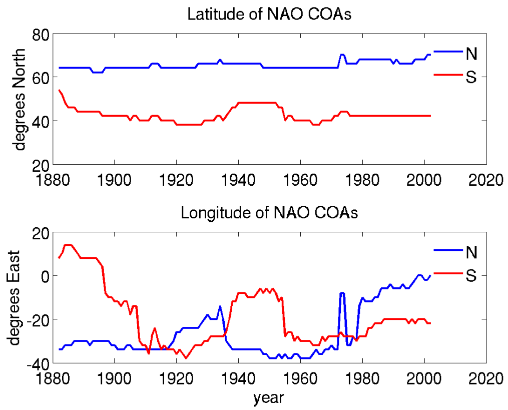
Secular variations in the NAO-precipitation relationship and the NAO Angle Index

Sliding correlation NAO - HKK precipitation and time series of the AI



Alternation of periods of **strong and weak influence** of the NAO on winter precipitation over the HKK

The spatial pattern of the **NAO changes in time**: position of NAO centers of action (COAs) shifts in longitude and latitude. **The Angle Index is a measure of these displacements**



The position of the NAO COAs regulates the strength of the NAO-precipitation relationship

- ✓ **High AI: weak control** of the NAO on HKK precipitation
- ✓ **Low AI: strong control** of the NAO on HKK precipitation

References

a. Precipitation

1. Palazzi, E., J. von Hardenberg, and A. Provenzale. 2013. Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios, J. Geophys. Res. Atmos., 118, 85–100, doi: 10.1029/2012JD018697

2. Palazzi E., J. von Hardenberg, S. Terzago, A. Provenzale. 2014. Precipitation in the Karakoram-Himalaya: A CMIP5 view, Climate Dynamics, doi: 10.1007/s00382-014-2341-z

b. Snow

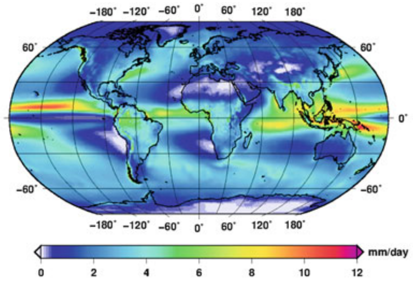
Terzago, S, J von Hardenberg, E Palazzi, A Provenzale. 2014. Snowpack changes in the Hindu-Kush Karakoram Himalaya from CMIP5 Global Climate Models, Journal of Hydrometeorology. doi: 10.1175/JHM-D-13-0196.1

c. Circulation

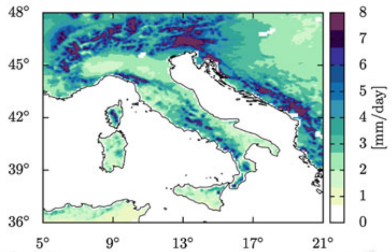
Filippi L, Palazzi E, von Hardenberg J, Provenzale A. 2014. Multidecadal Variations in the Relationship between the NAO and Winter Precipitation in the Hindu-Kush Karakoram. Journal of Climate. doi: 10.1175/JCLI-D-14-00286.1

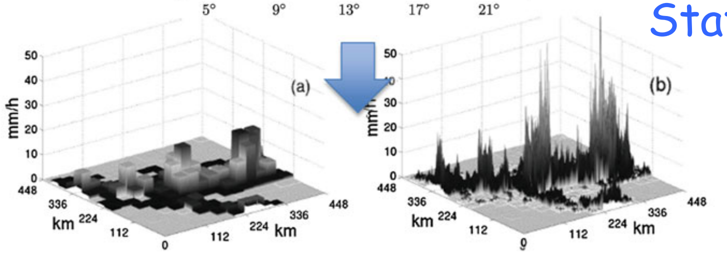
Conclusive thoughts
Modelling chain: a chain of uncertainties

Global climate model



Regional climate model





Statistical/stochastic downscaling

Uncertainties in the GCMs
(it is difficult to quantify the portion of uncertainties coming from different elements)

Dynamical downscaling

Uncertainties in the RCMs

Statistical/stochastic downscaling

Uncertainties related to other downscaling approaches

More uncertainties than strengths …

How do the uncertainties propagate across the chain?
How to quantify them?

Links with international initiatives: GEO-Gnome

- **GEO-GEOSS (Group on Earth Observation System of Systems)**
  - SBA – Ecosystems
    - **Task EC-01: Global Ecosystem Monitoring.** Task Coordinator: Italy
      - **Component EC-01-C3: Global Network for Observations and Information in Mountain Environments (GEO-GNOME)**

http://www.earthobservations.org/

Actions

- Identify and collect data, archives and portals which are already available (e.g. ICIMOD, Pyrenees Climate Change Observatory, NextData project)
- Identify the main scientific questions to be addressed, also stimulating new measurements and modelling actions
- Suggest and support concrete policy actions by the interaction between scientists of different king, stakeholders, local authorities and policy makers
- Develop capacity building strategies, especially in the most remote mountain areas.

Links with international initiatives: GEO-Gnome

http://www.earthobservations.org/

- **GEO-GEOSS (Group on Earth Observation System of Systems)**
  - SBA – Ecosystems
    - **Task EC-01: Global Ecosystem Monitoring.**
      Task Coordinator: Italy
      - **Component EC-01-C3: Global Network for Observations and Information in Mountain Environments (GEO-GNOME)**

Role	Member or PO	Implementing Entity
Lead (PoC)	Italy	CNR
Lead	Chile	University of Magallanes
Lead	Ecuador	MRECI
Lead	Germany	University Bayreuth
Lead	ICIMOD	ICIMOD
Lead	Italy	CNR
Lead	Nepal	NAST
Lead	Peru	CONDESAN
Lead	RCMRD	RCMRD
Lead	Spain	CMAOT
Lead	Switzerland	University of Bern
Lead	UNEP	UNEP - GRID-Arendal
Lead	UNOOSA	UNOOSA
GEO Sec Rep	GEO Secretariat	GEO
Contributor	Chile	INACH
Contributor	Chile	University of Magallanes
Contributor	ICIMOD	ICIMOD
Contributor	Italy	CNR
Contributor	Italy	EURAC
Contributor	Italy	Ev-K2-CNR
Contributor	Macedonia	PSI Hydrobiological Institute
Contributor	Norway	University of Bergen
Contributor	Pakistan	Ev-K2-CNR
Contributor	Pakistan	Ev-K2-CNR
Contributor	Peru	CONDESAN
Contributor	Spain	CMAOT
Contributor	Spain	CMAOT
Contributor	Spain	University of Barcelona
Contributor	United States	University of California
Contributor	UNOOSA	UNOOSA

Links with international initiatives: Belmont Calls

http://igfagcr.org/current-past-future-calls

- State and evolution of water resources in mountain areas
- Mountain ecosystems and biodiversity change
- High-resolution climate information in mountains and changes in natural hazards
- Efficient and open data and information distribution systems
- Impact of climate change on human health in the mountains
- Changes in the economic sector and sustainable development
- Societal changes in rural mountain areas and regional development.

Collaborative Research Action (CRA)

"Mountains as sentinels of change"

Proposers:

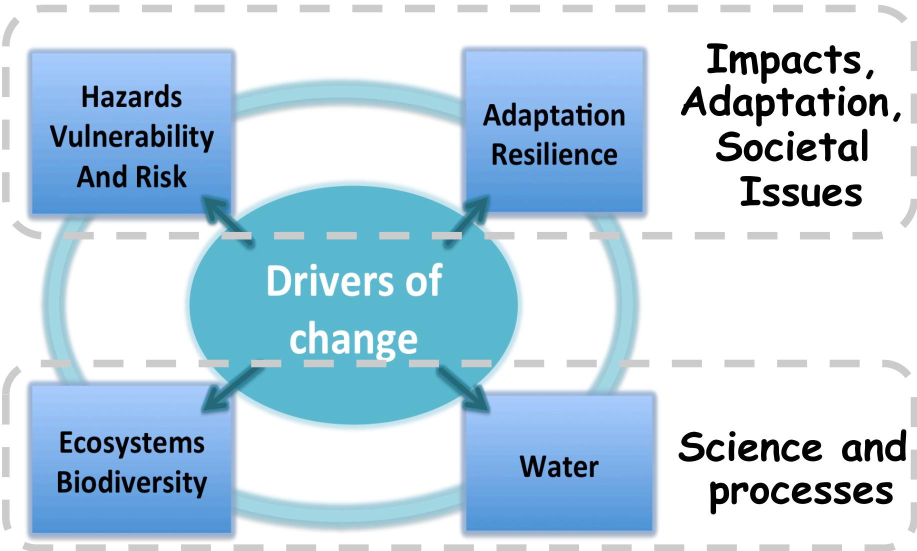
CNR-DTA (NextData Project), Italy
NSF, USA

Agencies that will support the call

Italy, US, Germany, France, UK, China, Brazil, Austria (in-kind)

Tentative timeline:

- **February 2015: call for pre-proposals**
- June 2015: call closes
- July 2015: Invite full proposals
- October 2015: full proposals due
- December 2015: Panel for decision (@AGU)
- March 2016: projects begin



HKH Workshop, November 7 2014, Kathmandu

Additional

<u>a. Precipitation</u> Projections EC-Earth model

1

EC-Earth GCM

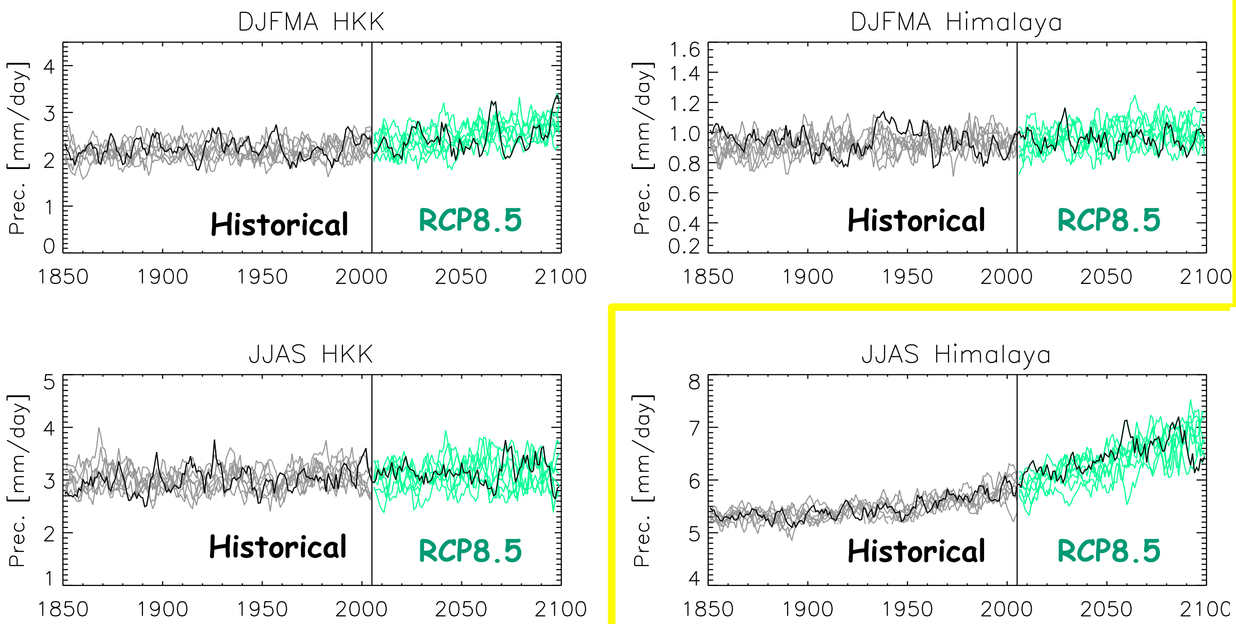
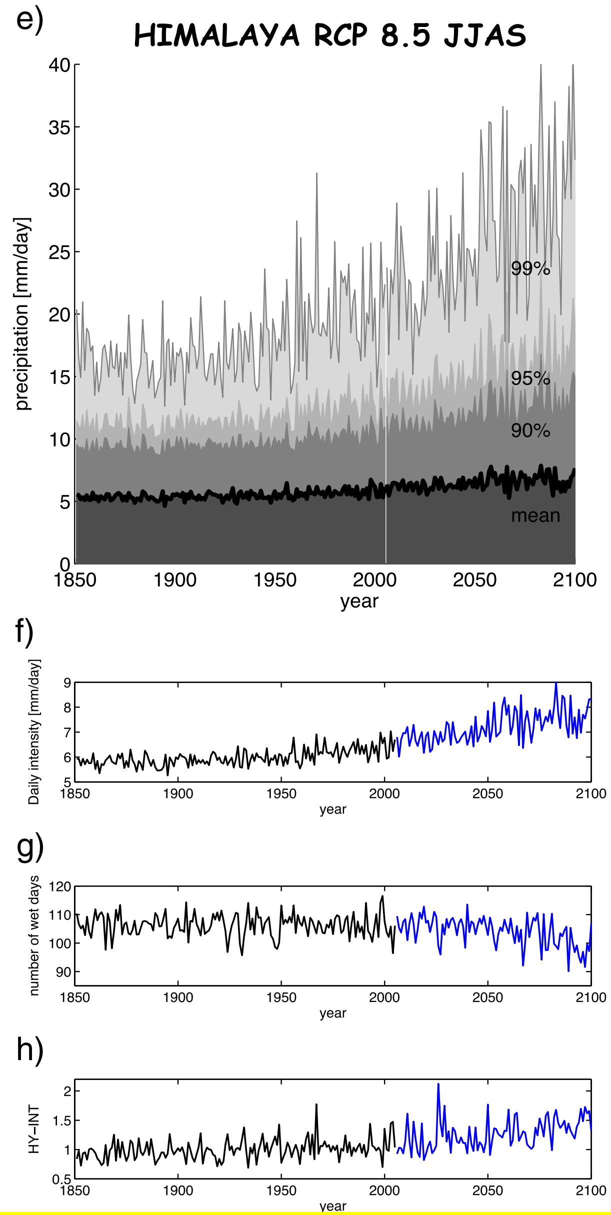


Figure 12. Same as Figure 11 but for the RCP 8.5 scenario.



HIMALAYA SUMMER

- Positive precipitation trend in the period 1950-2009
- Positive precipitation trend in the future scenario, associated with **an increase in wet extremes and daily intensity** and a **decrease in the number of rainy days**
- **Transition toward more episodic and intense monsoonal precipitation**