Modeling of the response of rivers to global change

Erika Coppola
ICTP, Trieste, Italy
coppolae@ictp.it

The background

IPCC Fourth Assessment Report: Climate Change 2007

Freshwater resources are among the systems and sectors that are **vulnerable** and have the potential to be **strongly impacted** by **climate change**

Warming observed over the past several decades is consistently **linked** to **changes** in the **hydrological cycle** such as

- **increasing** atmospheric **water vapour**
- **changing precipitation patterns**, **intensity** and **extremes**
- widespread **melting** of **snow** and **ice**
- **changes** in **soil moisture** and **runoff**

Climate models are consistent in projecting **precipitation increases** in the future in **high latitudes** and parts of the tropics, while in some **subtropical and lower mid-latitude** regions they are consistent in projecting **precipitation decreases**

By the **middle of the 21st century**, annual average river runoff and **water availability** --→ increase by 10-40% at **high latitudes** and in some **wet tropical areas** --→ decrease by 10-30% over some **dry regions at mid-latitudes** and in the **dry tropics**.
Many **semi-arid** and arid areas (e.g., the **Mediterranean** basin, **western USA**, **southern Africa** and **north-eastern Brazil**) are particularly **exposed** to the impacts of climate change and are projected to **suffer** a **decrease of water resources** due to climate change.

water supplies stored in **glaciers** and **snow cover** are projected to **decline**

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reducing water availability (through seasonal shift in stream flow, an increase in the ratio of winter to annual flows, and reductions in low flows) in **regions** supplied by melt-water from major mountain ranges, where more than **one-sixth of the world population** currently **live**.

Sea-level rise is projected to **extend** areas of **salinisation** of **groundwater** and estuaries, resulting in a **decrease** of **freshwater** availability for **humans** and **ecosystems** in **coastal areas**.

Higher water temperatures, **increased precipitation intensity** and **longer periods** of **low flows** are expected

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exacerbate many forms of **water pollution** (from sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as thermal pollution), with **negative** impacts on **ecosystems**, **human health** and **water system** reliability .

Climate change affects the **function** and **operation** of **existing water infrastructure** (including hydropower, structural flood defences, and irrigation systems) as well as **water management practices**.

Globally, **water demand** will **grow** in the coming decades primarily **due** to **population growth** and increasing affluence.

Regionally, **large changes** in **irrigation** water use as a result of climate changes are **expected**.

Current water management practices are **inadequate** to **cope** with the **negative impacts** of **climate change** on **water supply** reliability, **flood** risk, **health**, **energy** and aquatic **ecosystems**.

Economic emphasis ––>

Global Integration ––>

A1 storyline: World: market-oriented Economy: fastest per capita growth Population: 2050 peak, then decline Governance: strong regional inter-actions; income convergence Technology: three scenario groups: • **A1FI**: fossil intensive • **A1T**:non-fossil energy sources • **A1B**: balanced across all sources	**A2 storyline** World: differentiated Economy: regionally oriented; low-est per capita growth Population: continuously increasing Governance: Self-reliance with preservation of local identities Technology: slowest and most fragmented development
B1 storyline World: convergent Economy: service and information based; lower growth than A1 Population: same as A1 Governance: global solutions to economic, social and environmental sustainability Technology: clean and resource-efficient	**B2 storyline** World: local solutions Economy: intermediate growth Population: continuously increasing at lower rate than A2 Governance: local and regional solutions to environmental protec-tion and social equity Technology: More rapid than A2; less rapid, more diverse than A1/B1

Regional emphasis ––>

<–– Environmental emphasis

Characteristics of the four SRES storylines (based on Nakićenović and Swart., 25 2000).

The evidence

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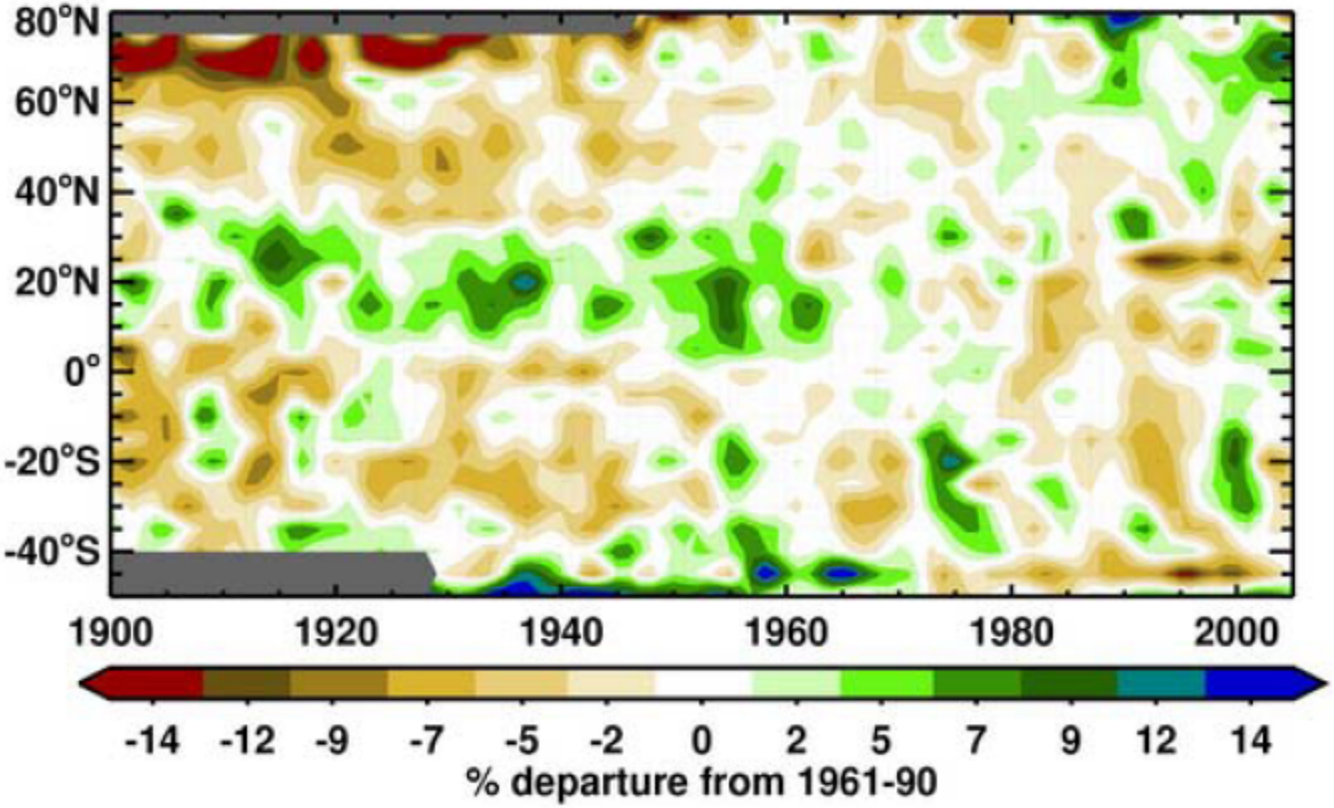
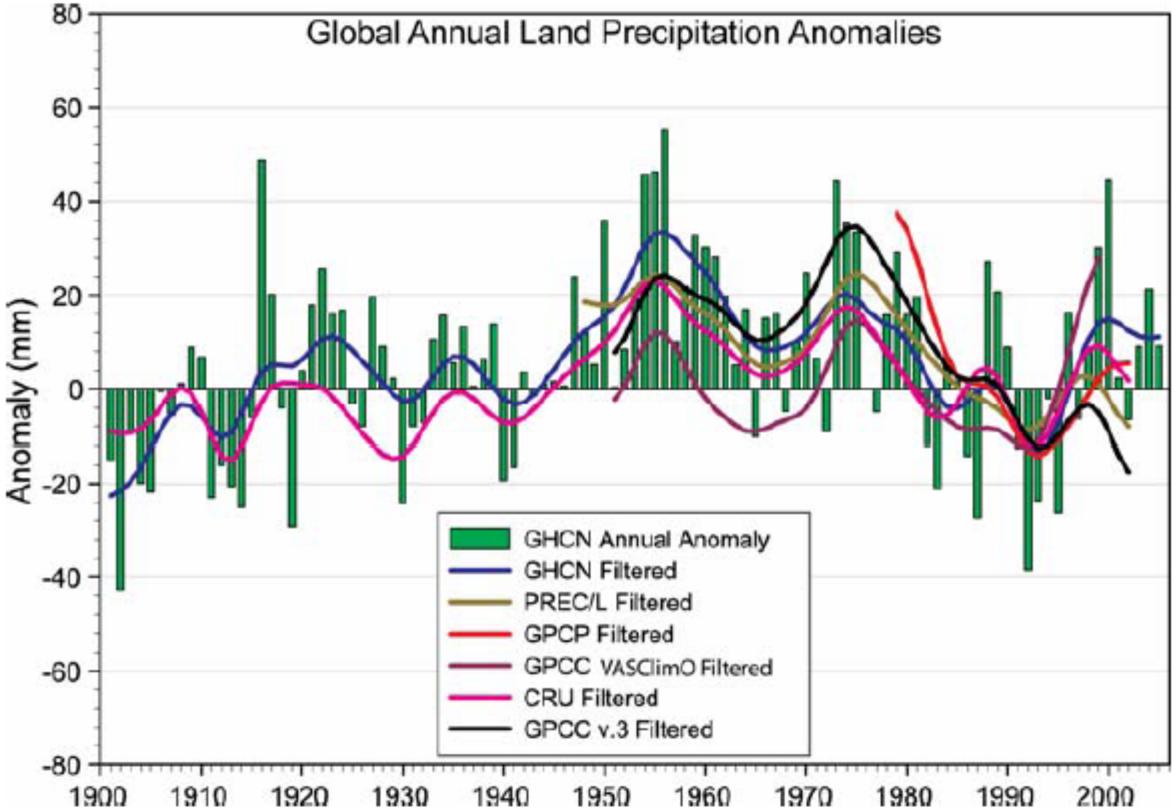
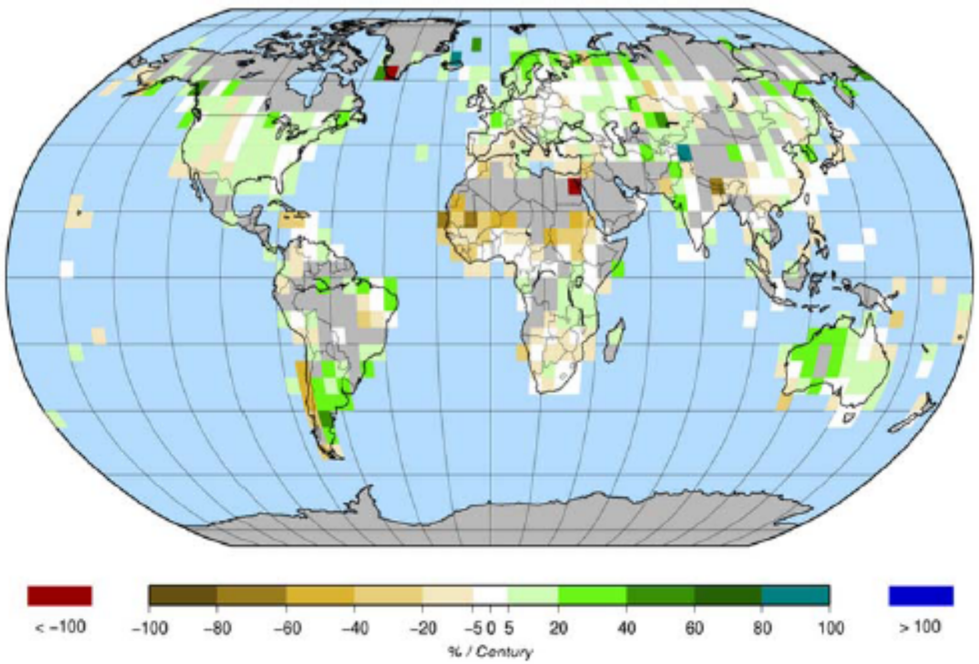
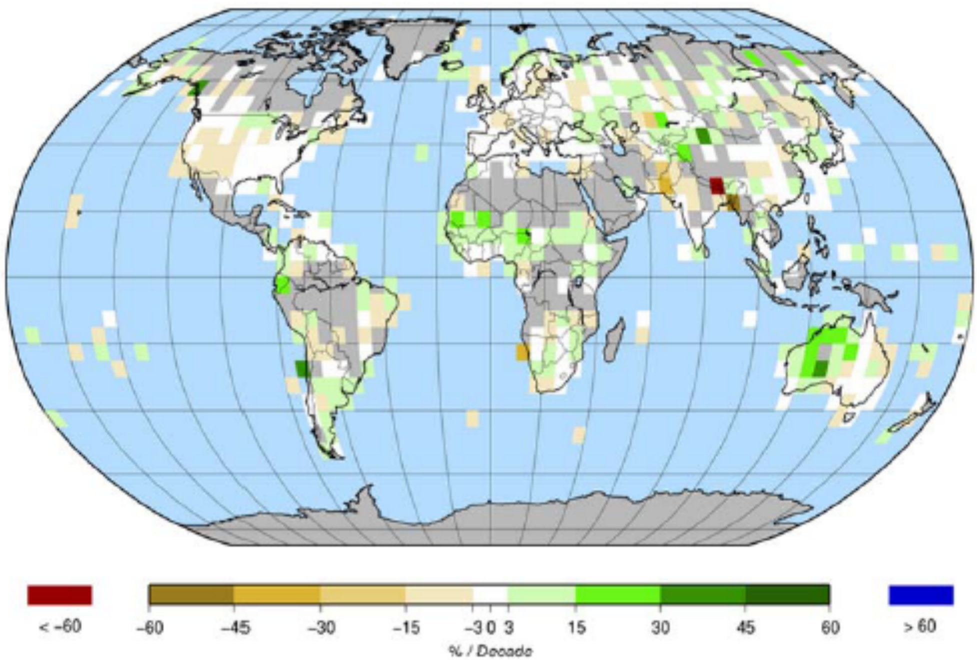


Average annual precpitation anomaly (%) over land relative to 1961-1990

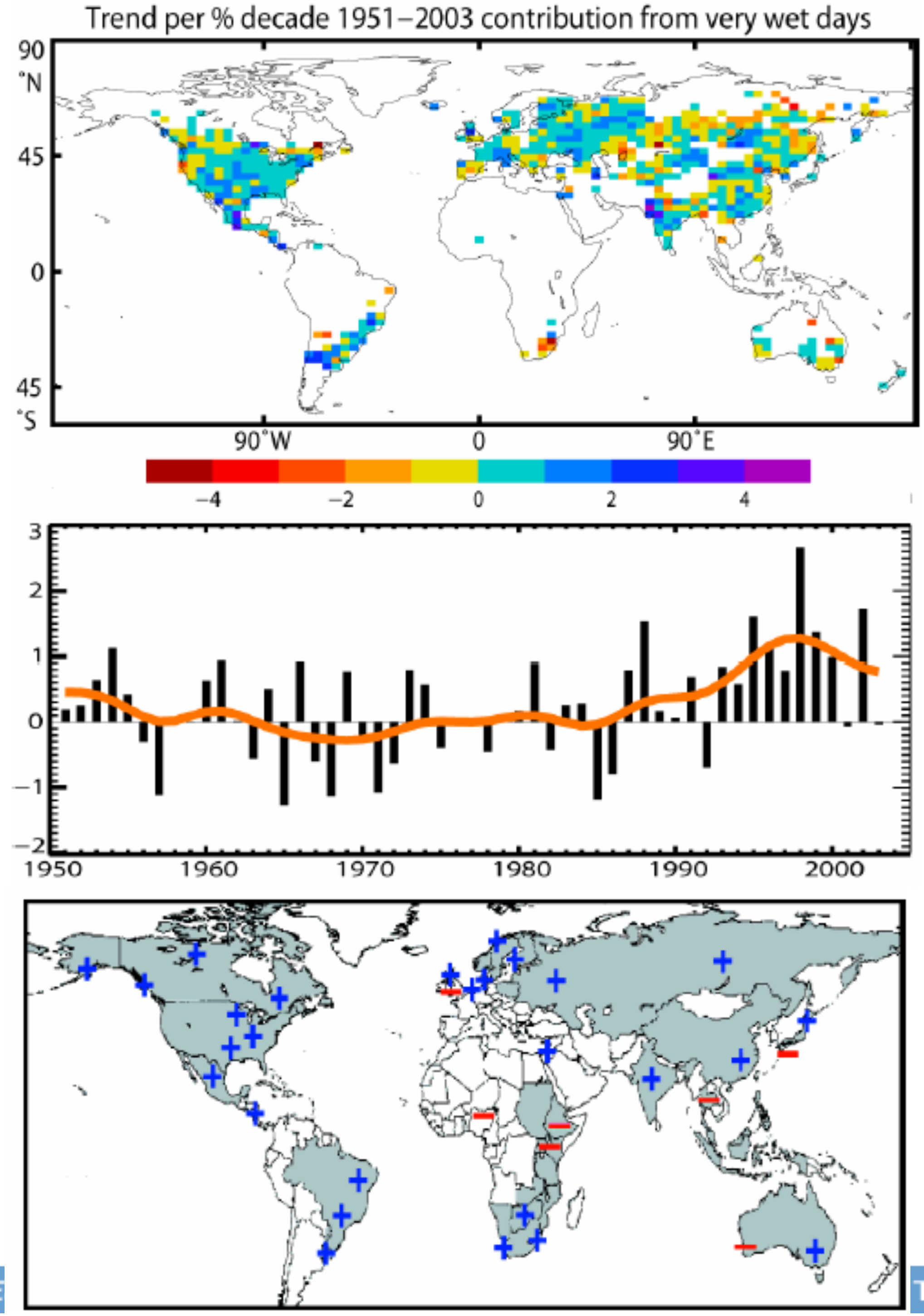
Annual global precipitation anomalies respect to 1981-2000



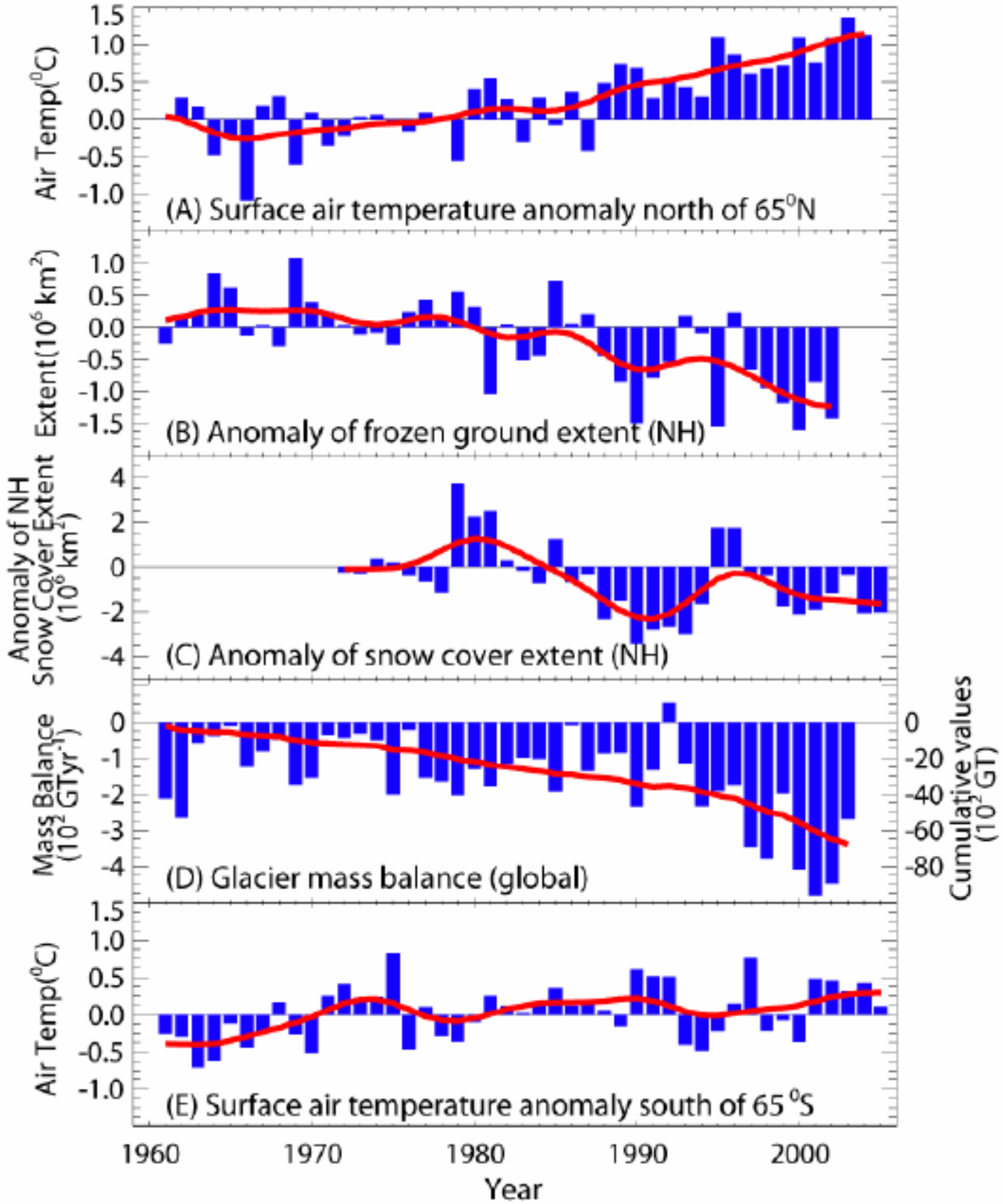




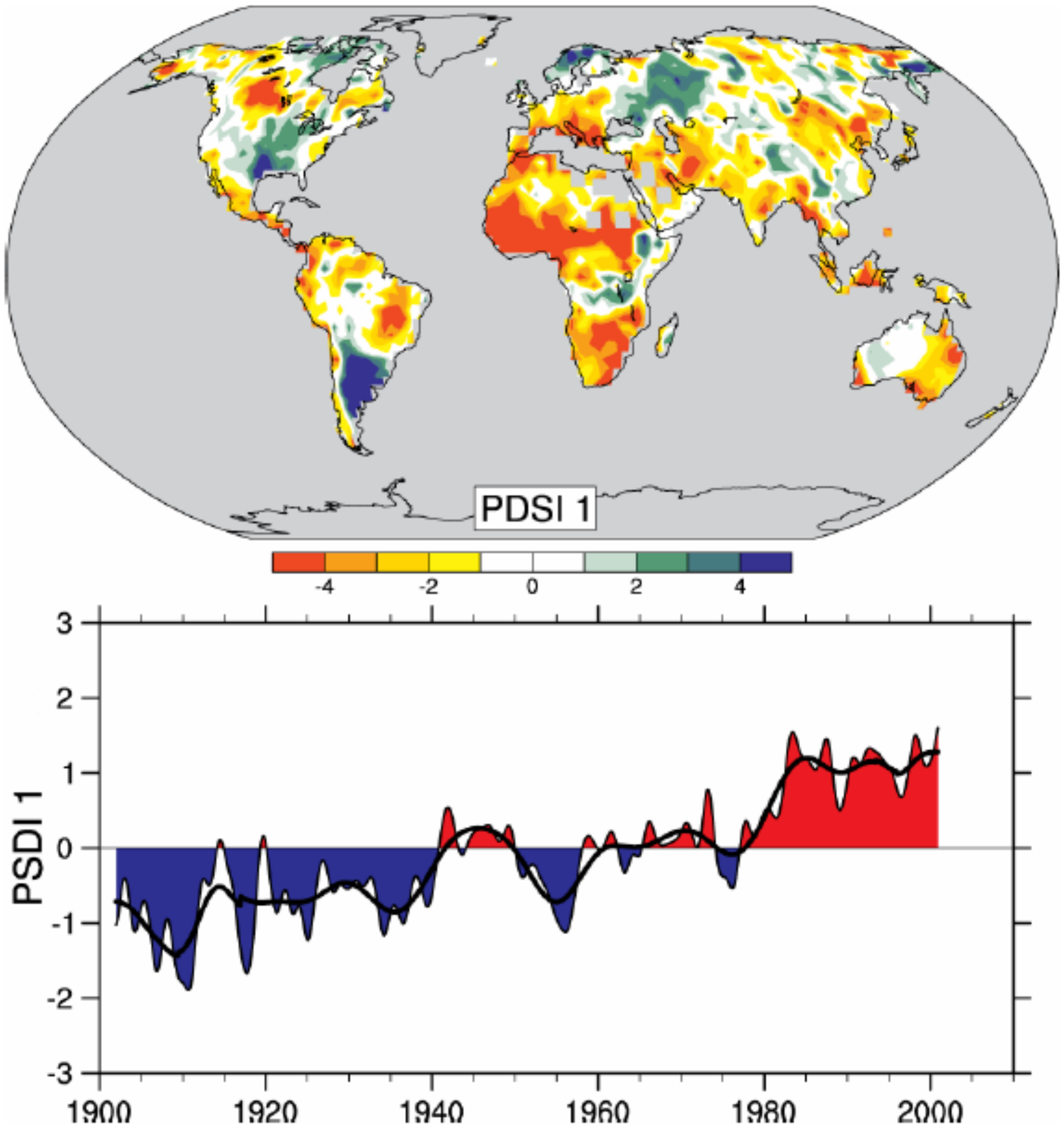
Trend of annual precipitation amounts, 1901-2005 (upper, % per century) and 1979-2005 (lower, % per decade), as a percentage of the 1961-1990 average, from GHCN station data. Grey areas have insufficient data to produce reliable trends.



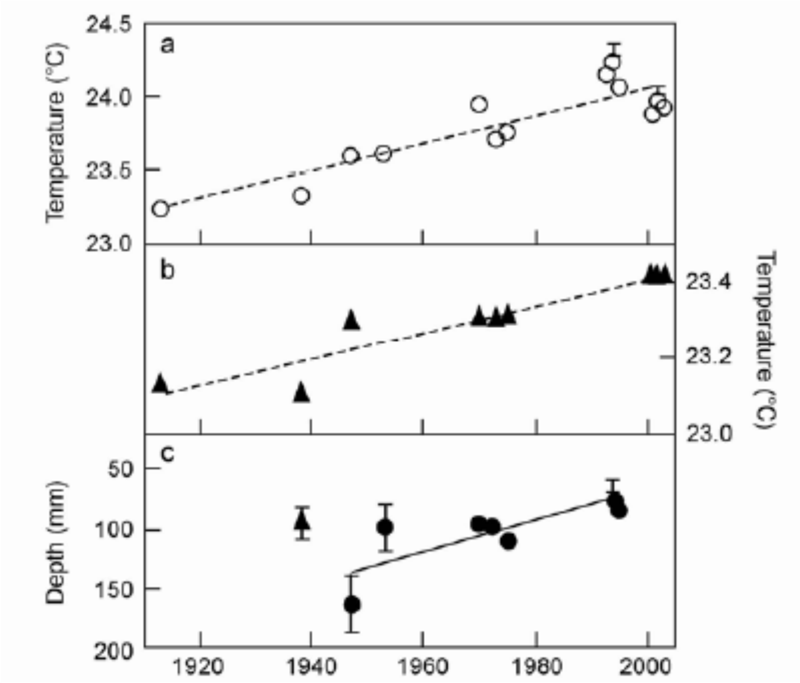
Upper panel shows observed ***trends*** *(% per decade, relative to 1961-1990) for 1951-2003 in the contribution to total annual* ***precipitation*** *from* ***very wet*** *days (95th percentile and above). Middle panel shows, for global annual precipitation, the percentage* ***change*** *of* ***very wet*** *daycontribution to the total, compared to the 1961-1990 average (after Alexander et al., 2006). Lower panel shows* ***regions where disproportionate changes*** *in* ***heavy*** *and* ***very heavy precipitation*** *were documented as either an increase (+) or decrease (–) compared to the change in annual and/or seasonal precipitation (updated from Groisman et al., 2005).*



Anomaly time series (departure from the long-term mean) of polar surface air temperature (A and E), Northern Hemisphere (NH) frozen ground extent (B), NH snow cover extent for March-April (C), global glacier mass balance (D). The solid red line in D denotes the cumulative global glacier mass balance; otherwise it represents the smoothed time series.

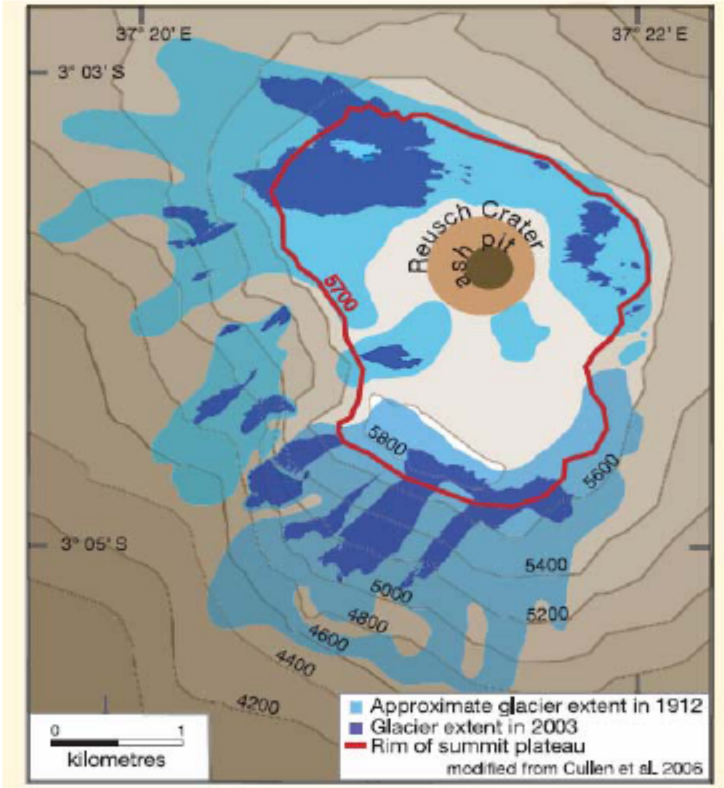


The most important spatial pattern (top) of the monthly ***Palmer Drought Severity Index*** *(PDSI) for 1900 to 2002. The PDSI is a prominent index of drought and* ***measures*** *the cumulative* ***deficit*** *(relative to local mean conditions) in* ***surface land moisture by*** *incorporating previous* ***precipitation*** *and* ***estimates*** *of* ***moisture*** *drawn into the atmosphere (****based*** *on* ***atmospheric temperatures****)* ***into*** *a* ***hydrological*** *accounting* ***system****. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (negative). The smooth black curve shows decadal variations. The time series approximately corresponds to a trend, and this pattern and its variations account for 67% of the linear trend of PDSI from 1900 to 2002 over the global land area. It therefore features widespread increasing African drought, especially in the Sahel, for instance. Note also the wetter areas, especially in eastern North and South America and northern Eurasia.*

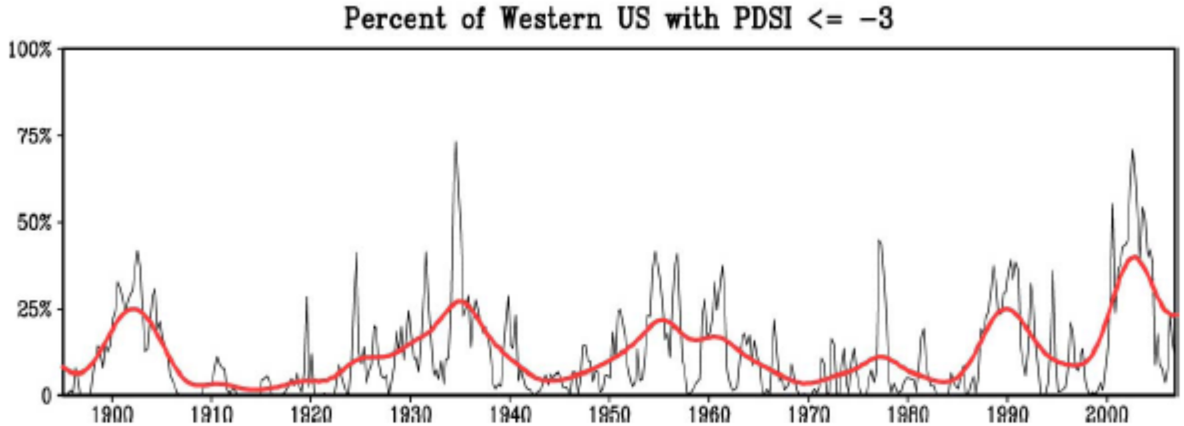


Historical and recent measurements from Lake Tanganyika, East Africa: (a) upper mixed layer (surface water) temperatures; (b) deep-water (600 m) temperatures; (c) depth of the upper mixed layer. (O'Reilly et al., 2003).

Decrease in surface area of Mt. Kilimanjaro glaciers from 1912 to 2003 (modified from Cullen et al., 2006).



Drought and climatic changes in the Colorado River Basin



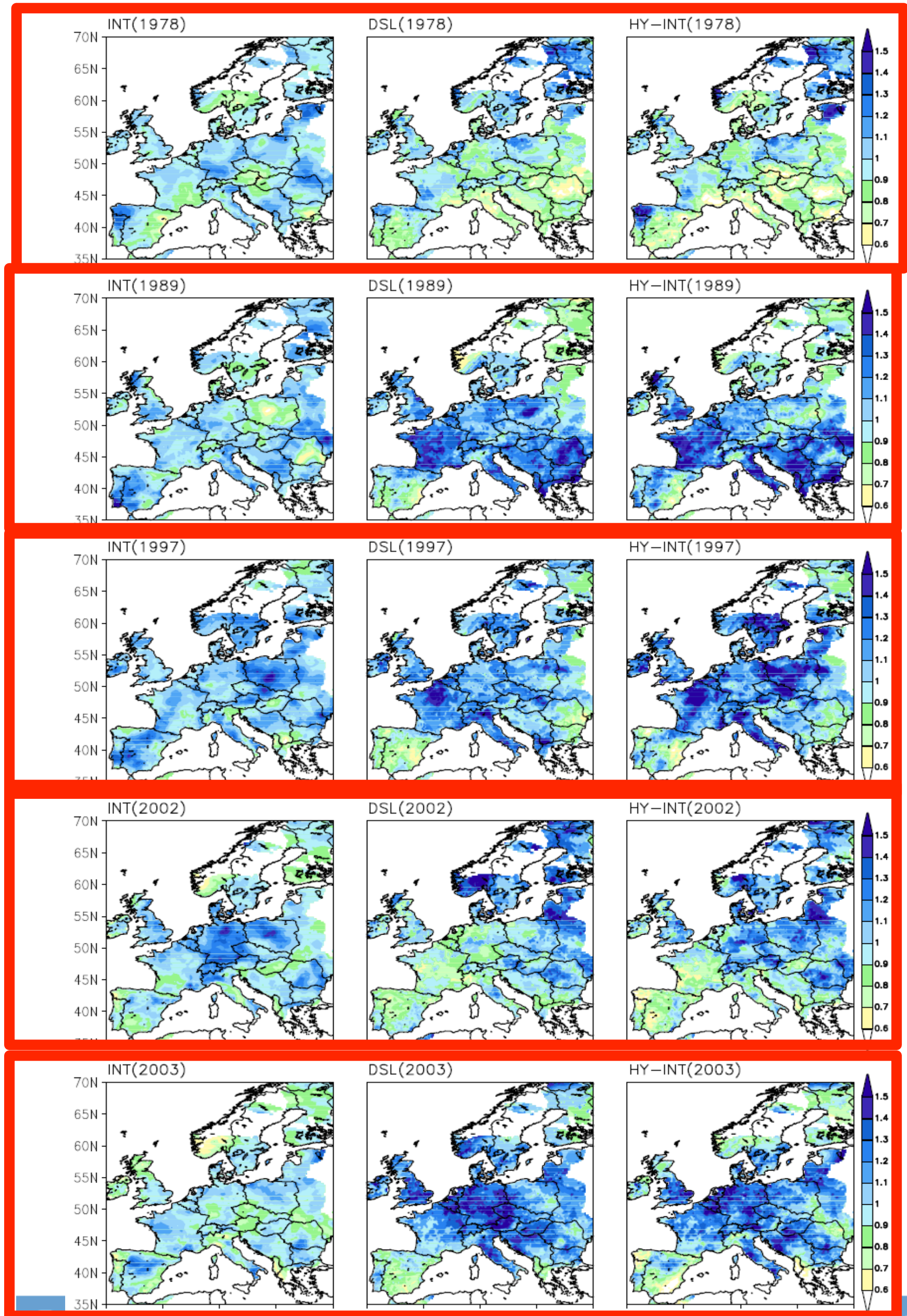
The areal percentage under severe drought conditions in seventeen states of the Western U.S. (Figure courtesy Jon Eischeid, NOAA/CIRES) Note: PDSI refers to the Palmer Drought Severity Index

Hydroclimatic Intensity index HY-INT

HY-INT = INT x DSL

Increase of HY-INT measures a dominant increase of INT, DSL or both. In fact, larger increases of HY-INT would occur when both INT and DSL increase and this would register a **change in the characteristics of the hydrologic cycle**.

F. Giorgi, E.-S. Im, E. Coppola, N.S. Diffenbaugh, X.J. Gao , L. Mariotti, Y. Shi. **Higher hydroclimatic intensity with global warming**, *Journal of Climate* 2011 ; e-View doi: 10.1175/2011JCLI3979.1



1978: example of a year with relatively *normal conditions*;

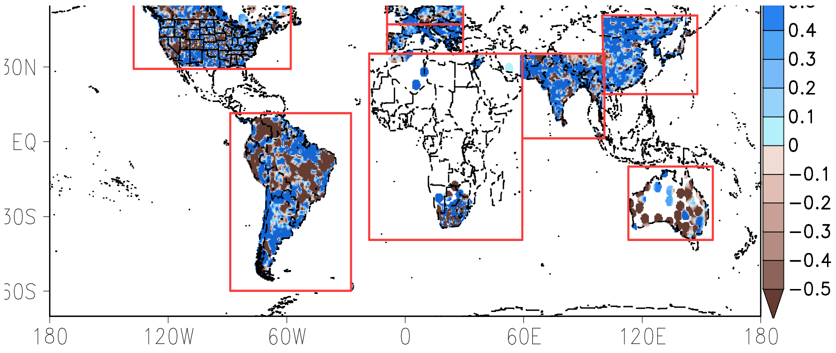
1989: example of a year with high HY-INT values over central and *eastern Europe* mostly due to relatively *dry conditions* (high DSL, Luterbacher et all, 2004);

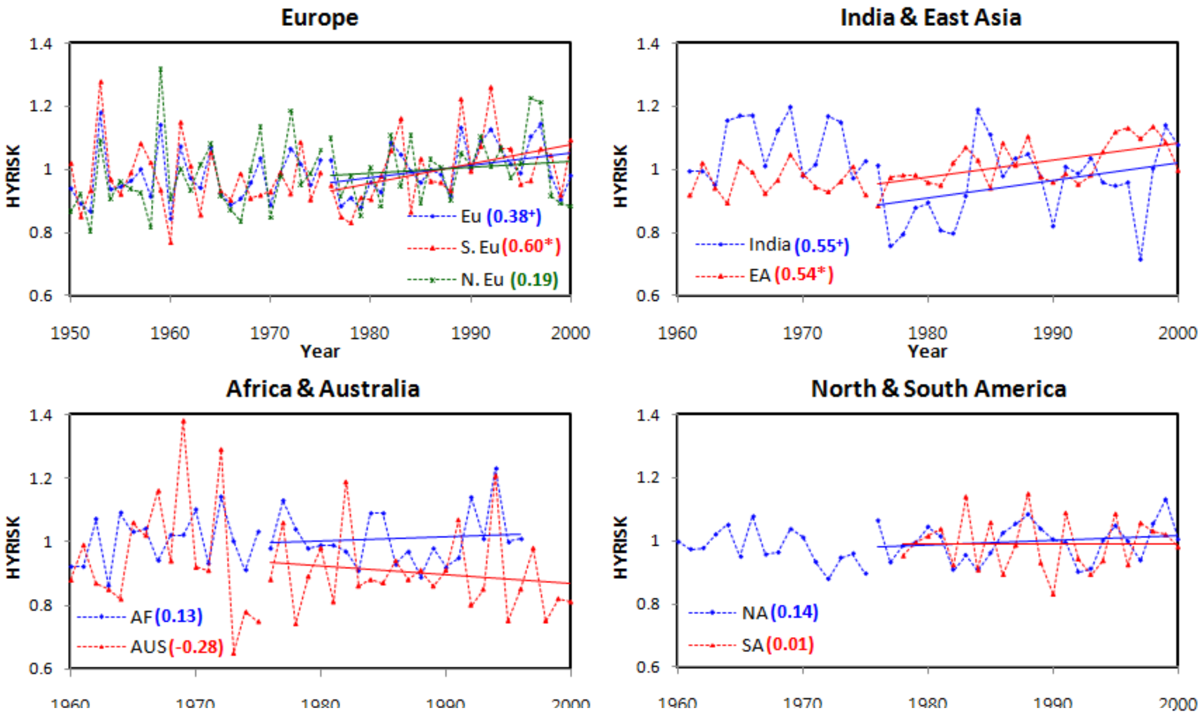
1997; example of year with high HY-INT due to relatively *dry conditions over France* and Italy and wet conditions (high INT) over northeastern Europe (Barredo, 2007);

2002: example of year with high HY-INT due to relatively *wet conditions over central Europe* (Barredo, 2007);

2003: example of year with high HY-INT due to relatively *dry conditions over central Europe* (Beniston, 2004; Schar, 2004).

OBS





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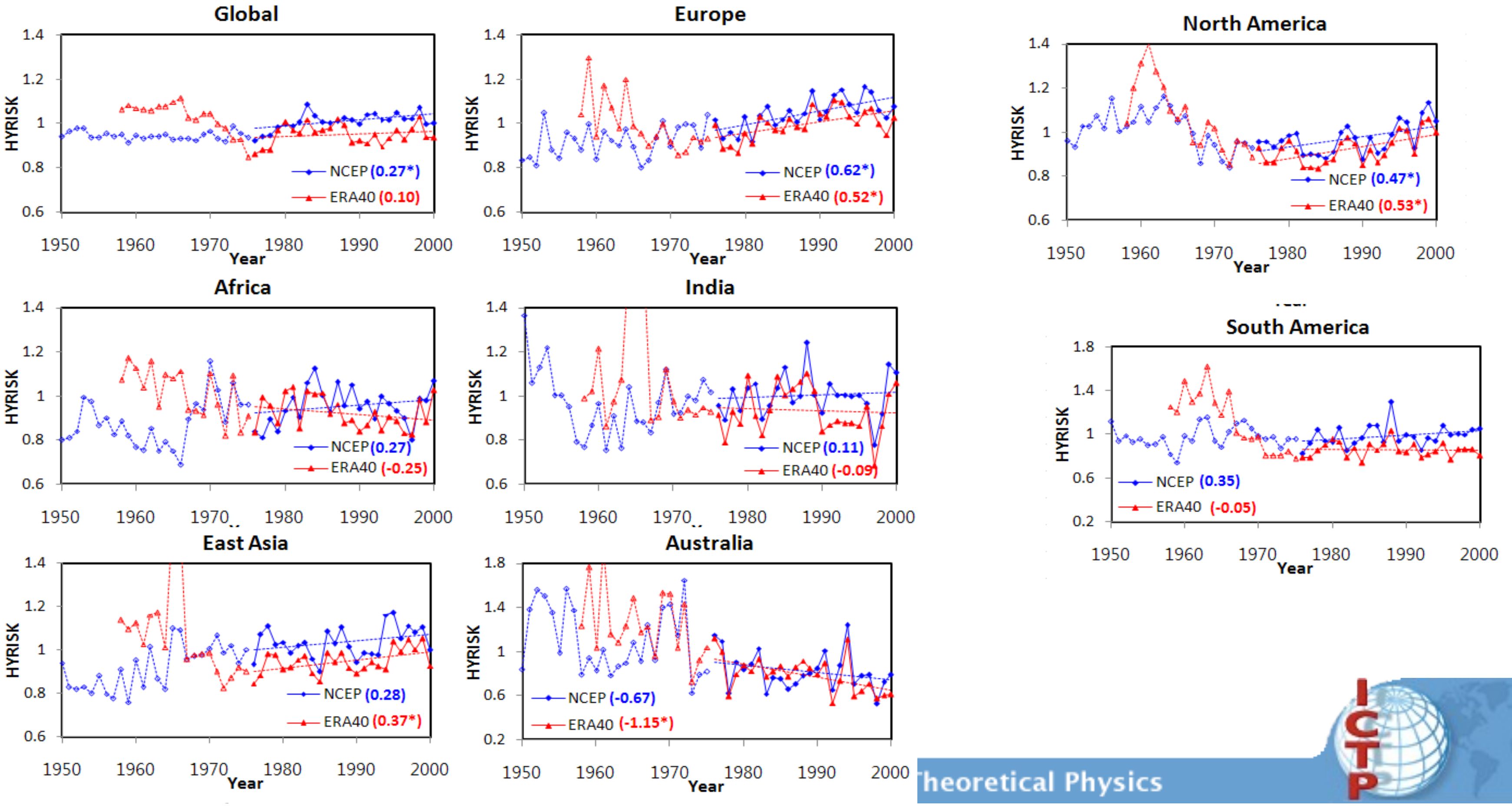
Reanalysis



Theoretical Physics

The model projections

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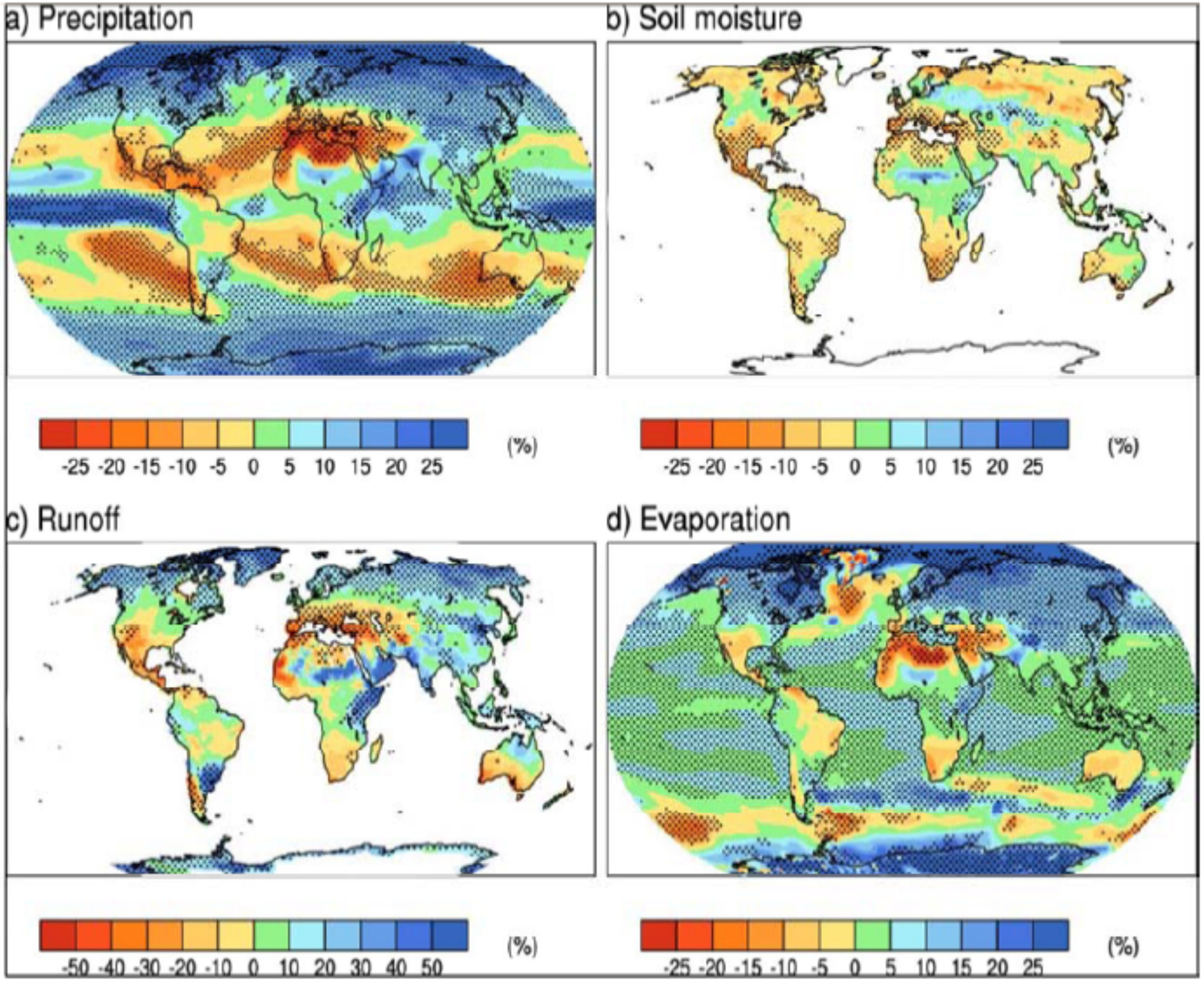
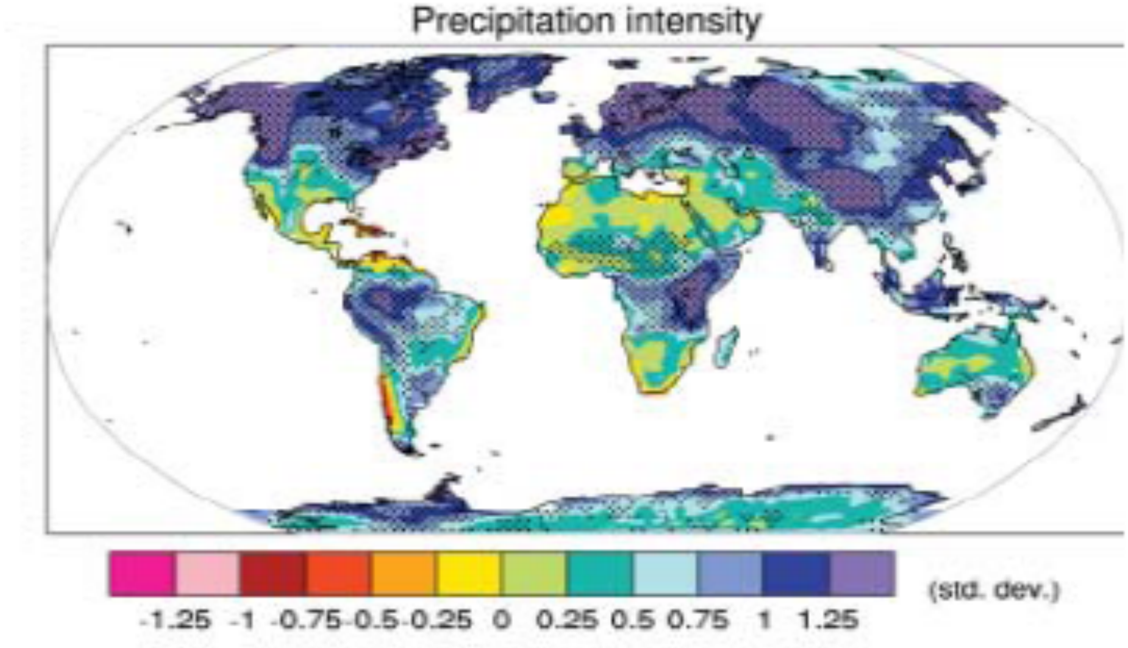
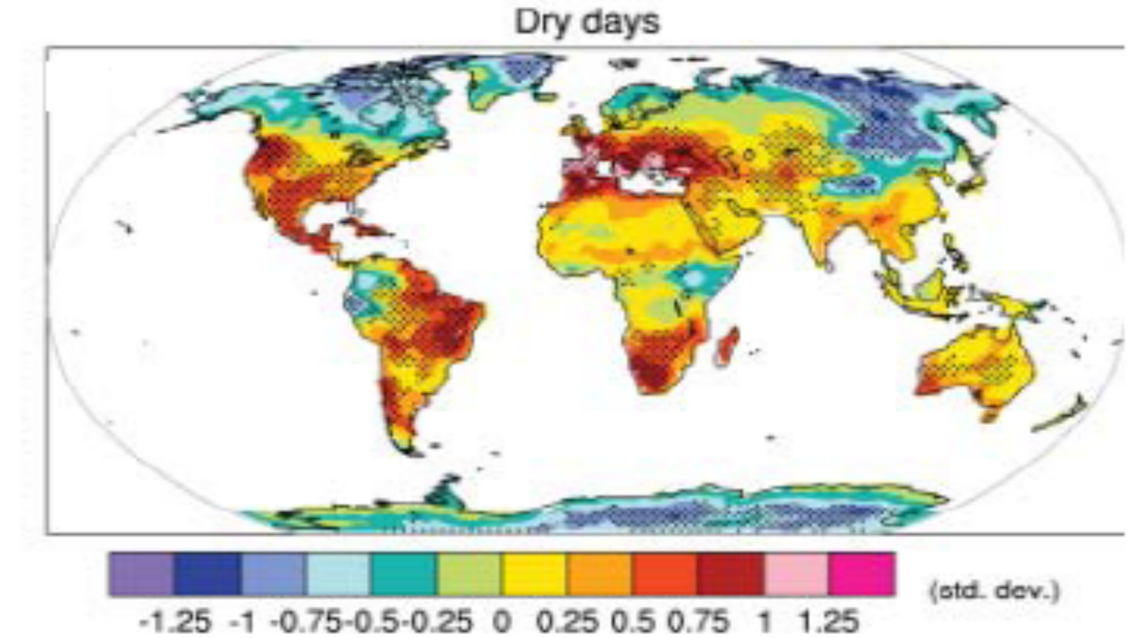


Fifteen model mean changes in a) precipitation (%), b) soil moisture content (%), c) runoff (%), and d) evaporation (%). To indicate consistency of sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. **Changes** are annual means for the scenario **SRES A1B**, for the period **2080–2099 relative** to **1980–1999**. Soil moisture and runoff changes are shown at land points with valid data from at least 10 models.

Changes in extremes based on multi-model simulations from nine global coupled climate models in 2080–2099 minus 1980–1999 for the A1B scenario



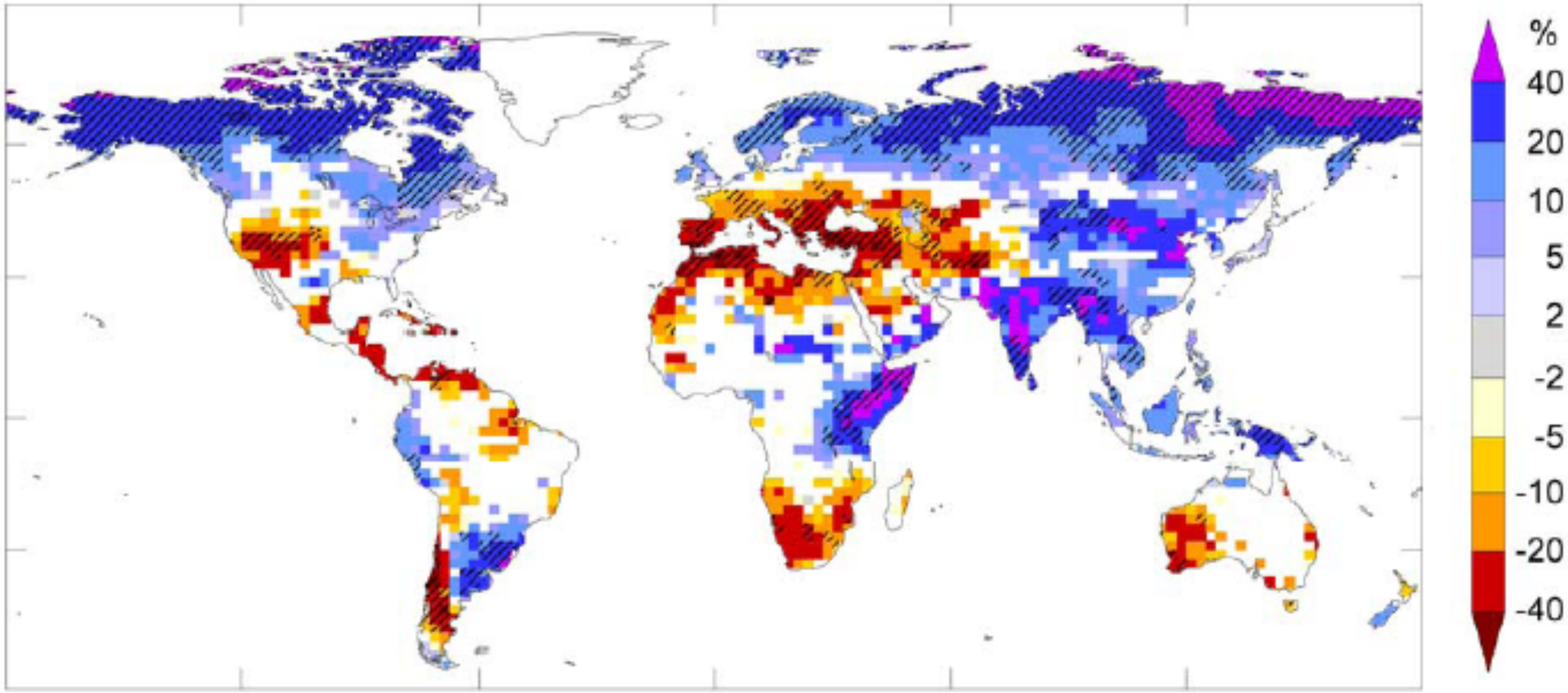
precipitation intensity (defined as the annual total precipitation divided by the number of wet days)



changes in spatial patterns of dry days (defined as the annual maximum number of consecutive dry days)

Physics

Changes in annual runoff from an ensemble of 12 models for the period 2090-2099, relative to 1980-1999



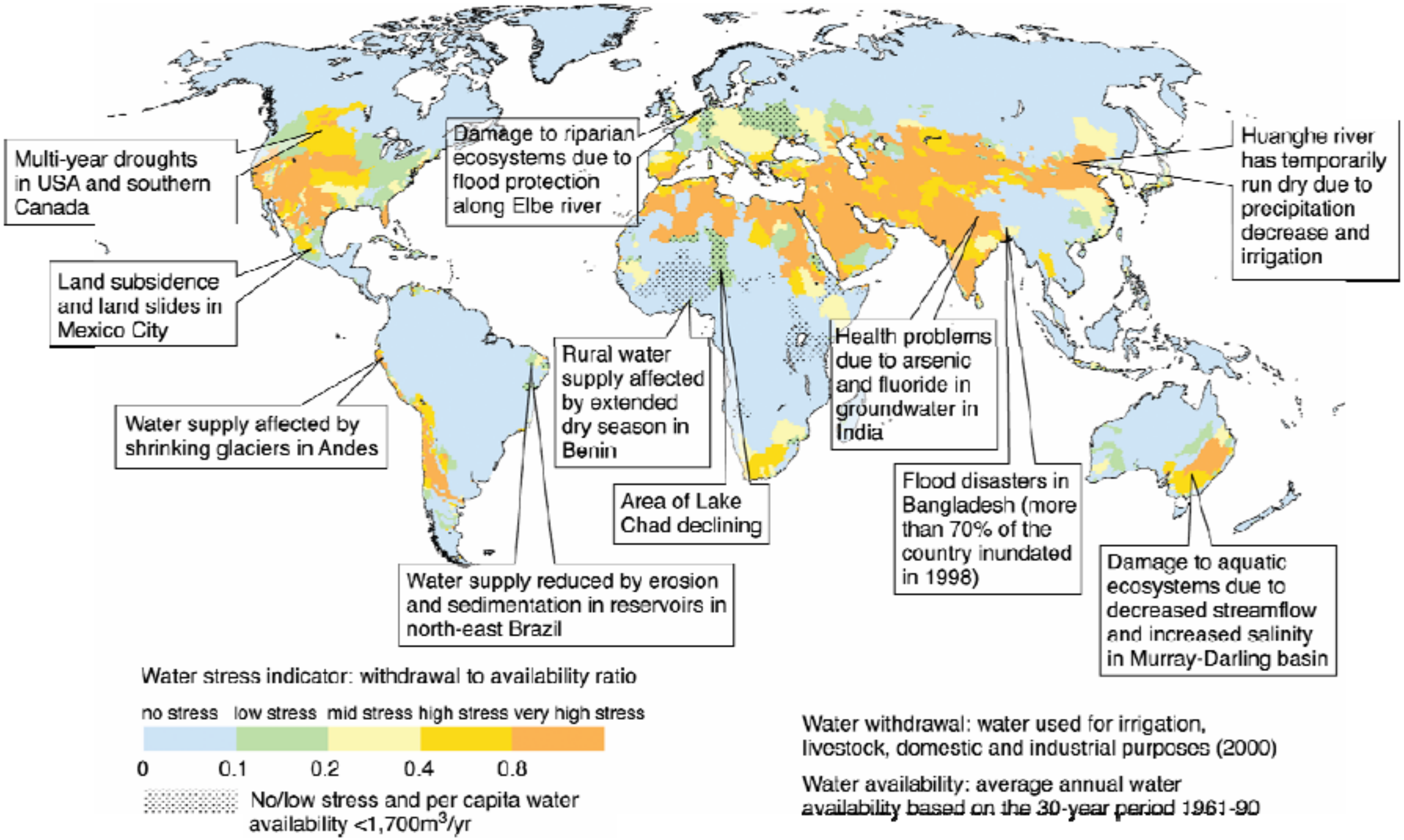
Possible impacts of climate change due to changes in extreme precipitation-related weather and climate events

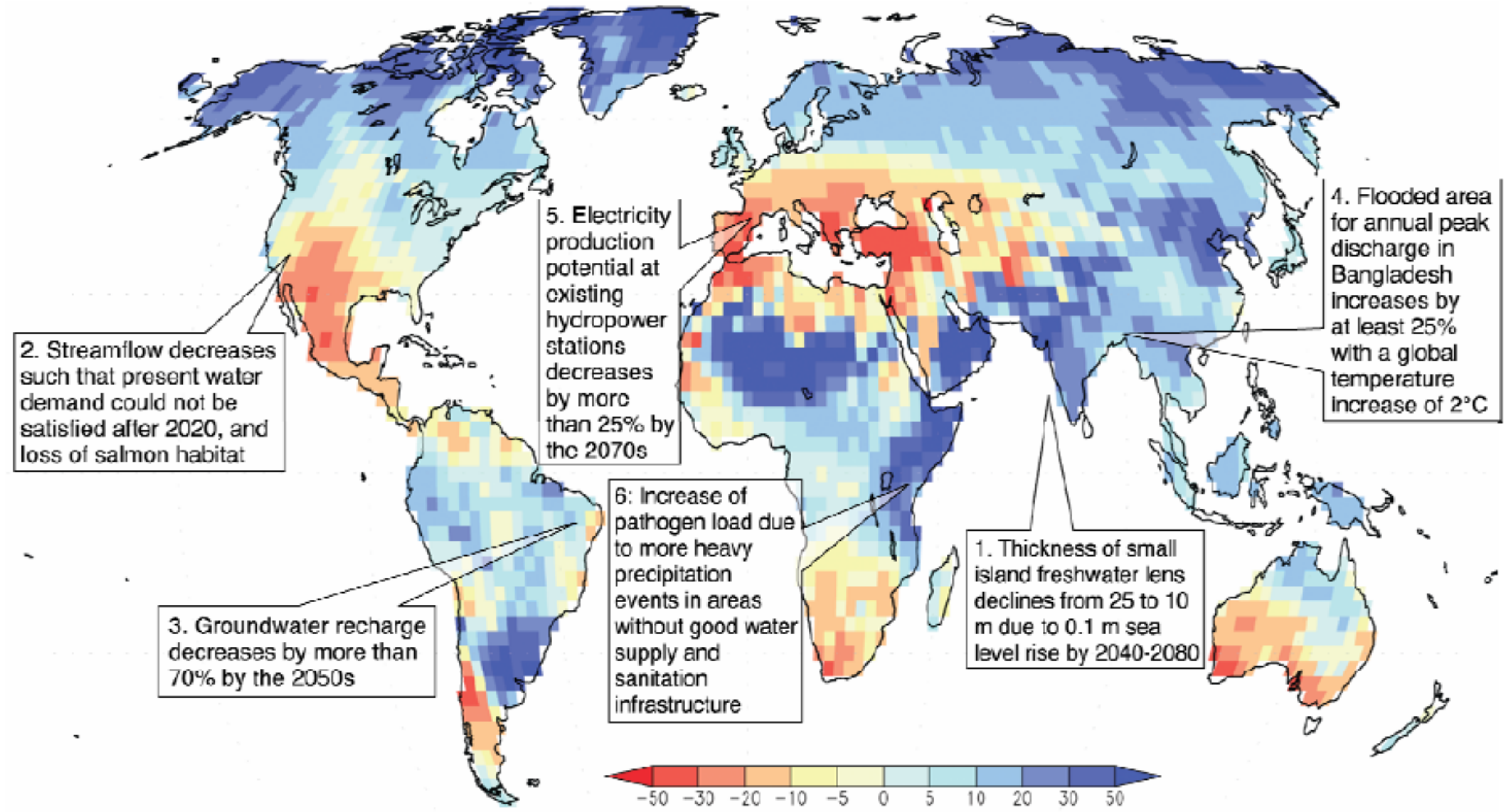
Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems [4.4, 5.4]	**Water resources [3.4]**	**Human health [8.2]**	**Industry, settlements and society [7.4]**
Heavy precipitation events: frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation, lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration

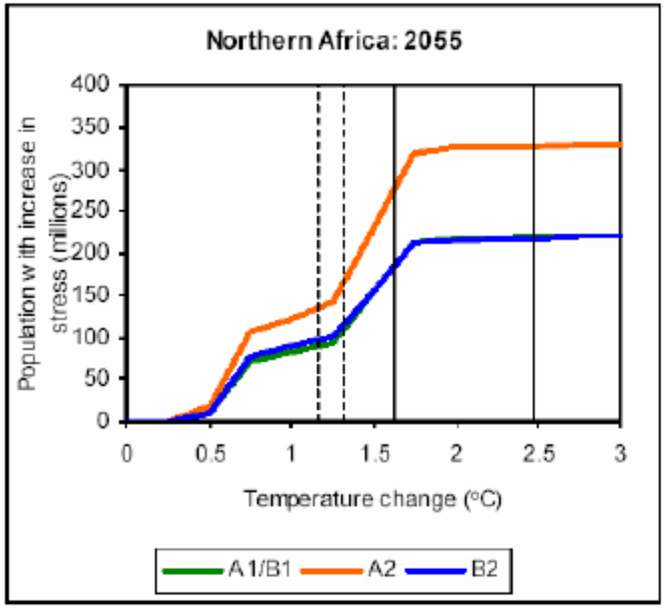
Observed changes in runoff/streamflow, lake levels and floods/droughts

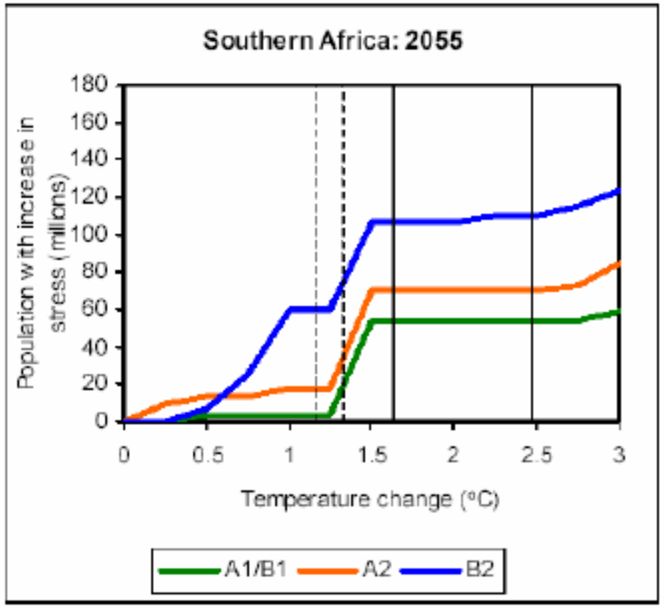
Environ-mental factor	Observed changes	Time period	Location
Runoff/ Streamflow	Annual increase of 5%, winter increase of 25 to 90%, increase in winter base flow due to increased melt and thawing permafrost	1935-1999	Arctic Drainage Basin: Ob, Lena, Yenisey, Mackenzie
	1 to 2 week earlier peak streamflow due to earlier warming-driven snow melt	1936-2000	Western North America, New England, Canada, northern Eurasia
Runoff increase in glacial basins in Cordillera Blanca, Peru	23% increase in glacial melt	2001-4 vs. 1998-9	Yanamarey Glacier catchment
	143% increase	1953-1997	Llanganuco catchment
	169% increase	2000-2004	Artesonraju catchment
Floods	Increasing catastrophic floods of frequency (0.5 to 1%) due to earlier break-up of river-ice and heavy rain	Last years	Russian Arctic rivers

Floods	Increasing catastrophic floods of frequency (0.5 to 1%) due to earlier break-up of river-ice and heavy rain	Last years	Russian Arctic rivers
Droughts	29% decrease in annual maximum daily streamflow due to temperature rise and increased evaporation with no change in precipitation	1847-1996	Southern Canada
	Due to dry and unusually warm summers related to warming of western tropical Pacific and Indian Oceans in recent years	1998-2004	Western USA
Water temperature	0.1 to 1.5°C increase in lakes	40 years	Europe, North America, Asia (100 stations)
	0.2 to 0.7°C increase (deep water) in lakes	100 years	East Africa (6 stations)
Water chemistry	Decreased nutrients from increased stratification or longer growing period in lakes and rivers	100 years	North America, Europe, Eastern Europe, East Africa (8 stations)
	Increased catchment weathering or internal processing in lakes and rivers.	10-20 years	North America, Europe (88 stations)


Multi-year droughts in USA and southern Canada
Damage to riparian ecosystems due to flood protection along Elbe river
Huanghe river has temporarily run dry due to precipitation decrease and irrigation
Land subsidence and land slides in Mexico City
Rural water supply affected by extended dry season in Benin
Health problems due to arsenic and fluoride in groundwater in India
Water supply affected by shrinking glaciers in Andes
Area of Lake Chad declining
Flood disasters in Bangladesh (more than 70% of the country inundated in 1998)
Damage to aquatic ecosystems due to decreased streamflow and increased salinity in Murray-Darling basin
Water supply reduced by erosion and sedimentation in reservoirs in north-east Brazil
Water stress indicator: withdrawal to availability ratio
no stress low stress mid stress high stress very high stress
0 0.1 0.2 0.4 0.8
No/low stress and per capita water availability <1,700m³/yr
Water withdrawal: water used for irrigation, livestock, domestic and industrial purposes (2000)
Water availability: average annual water availability based on the 30-year period 1961-90


5. Electricity production potential at existing hydropower stations decreases by more than 25% by the 2070s
4. Flooded area for annual peak discharge in Bangladesh increases by at least 25% with a global temperature increase of 2°C
2. Streamflow decreases such that present water demand could not be satisfied after 2020, and loss of salmon habitat
6: Increase of pathogen load due to more heavy precipitation events in areas without good water supply and sanitation infrastructure
1. Thickness of small island freshwater lens declines from 25 to 10 m due to 0.1 m sea level rise by 2040-2080
3. Groundwater recharge decreases by more than 70% by the 2050s
−50 −30 −20 −10 −5 0 5 10 20 30 50



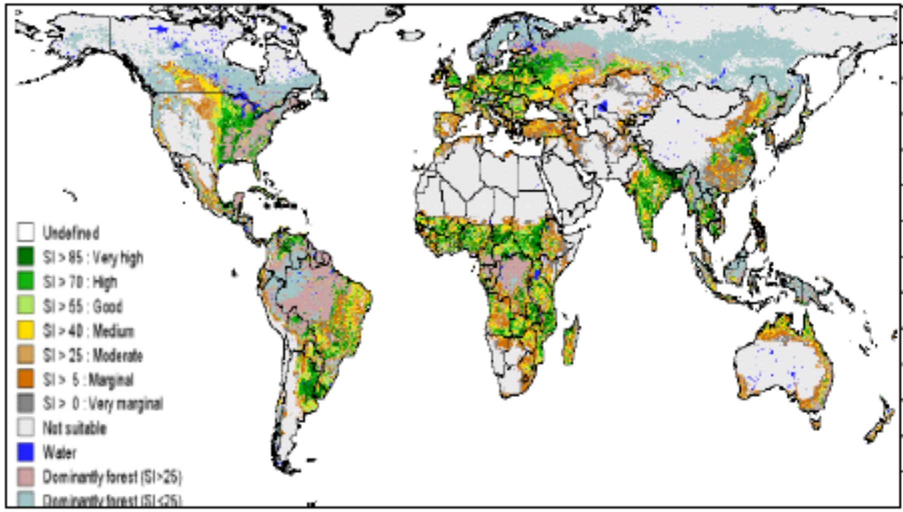


Number of people (millions) with an increase in water stress (Arnell, 2006b). Scenarios are all derived from HadCM3 and the red, green and blue lines relate to different Population projections.

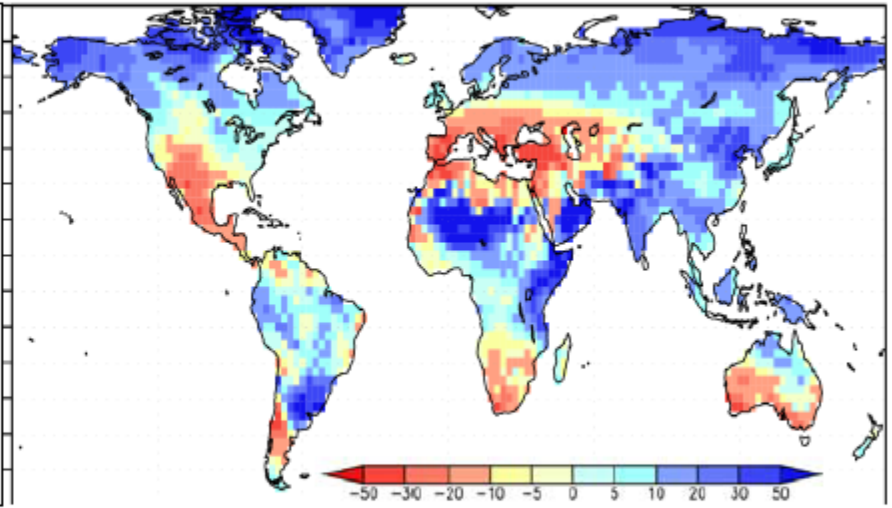
Forest ecosystems in boreal Asia would suffer from floods and increased volume of Runoff associated with melting of permafrost regions

The projected change of permafrost boundary in North Asia due to climate change by 2100 (FNCRF, 2006).

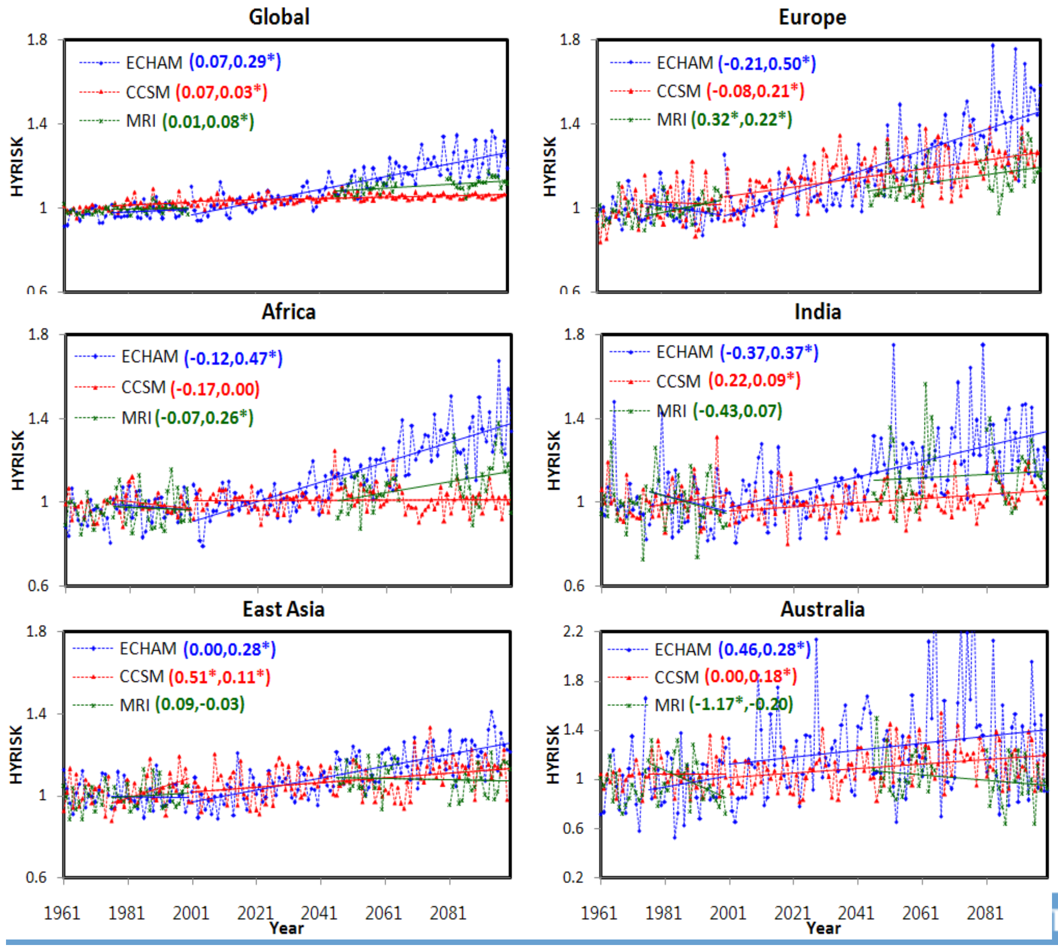
Current suitability for rain-fed crops

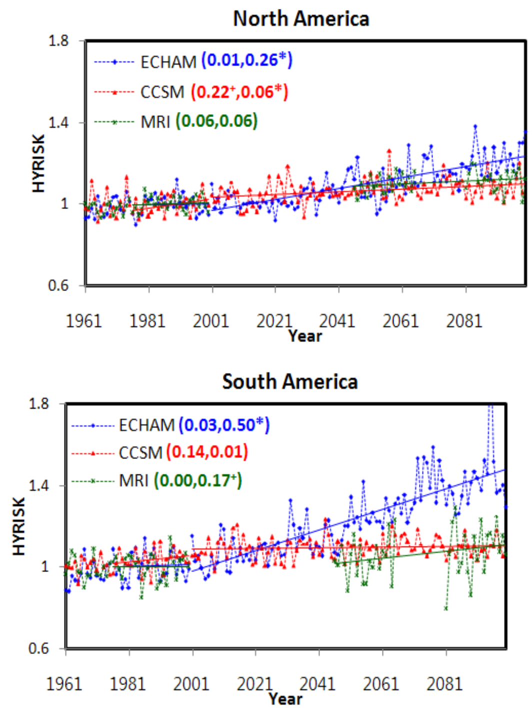


Ensemble mean percentage change of annual mean runoff



Global models





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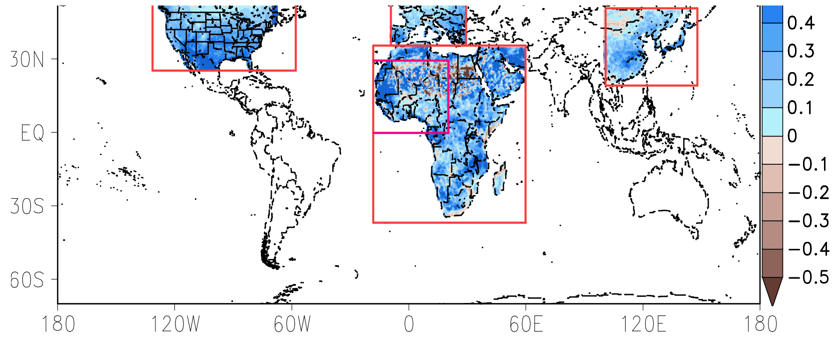
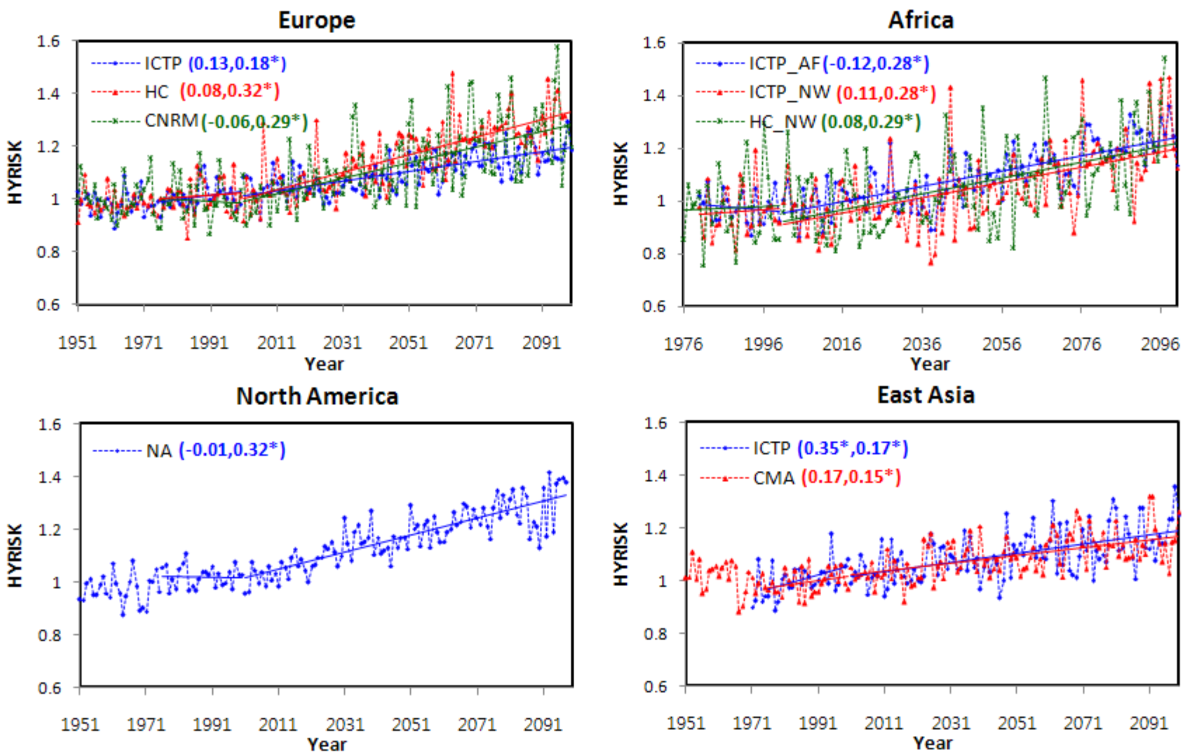
Theor



Regional models



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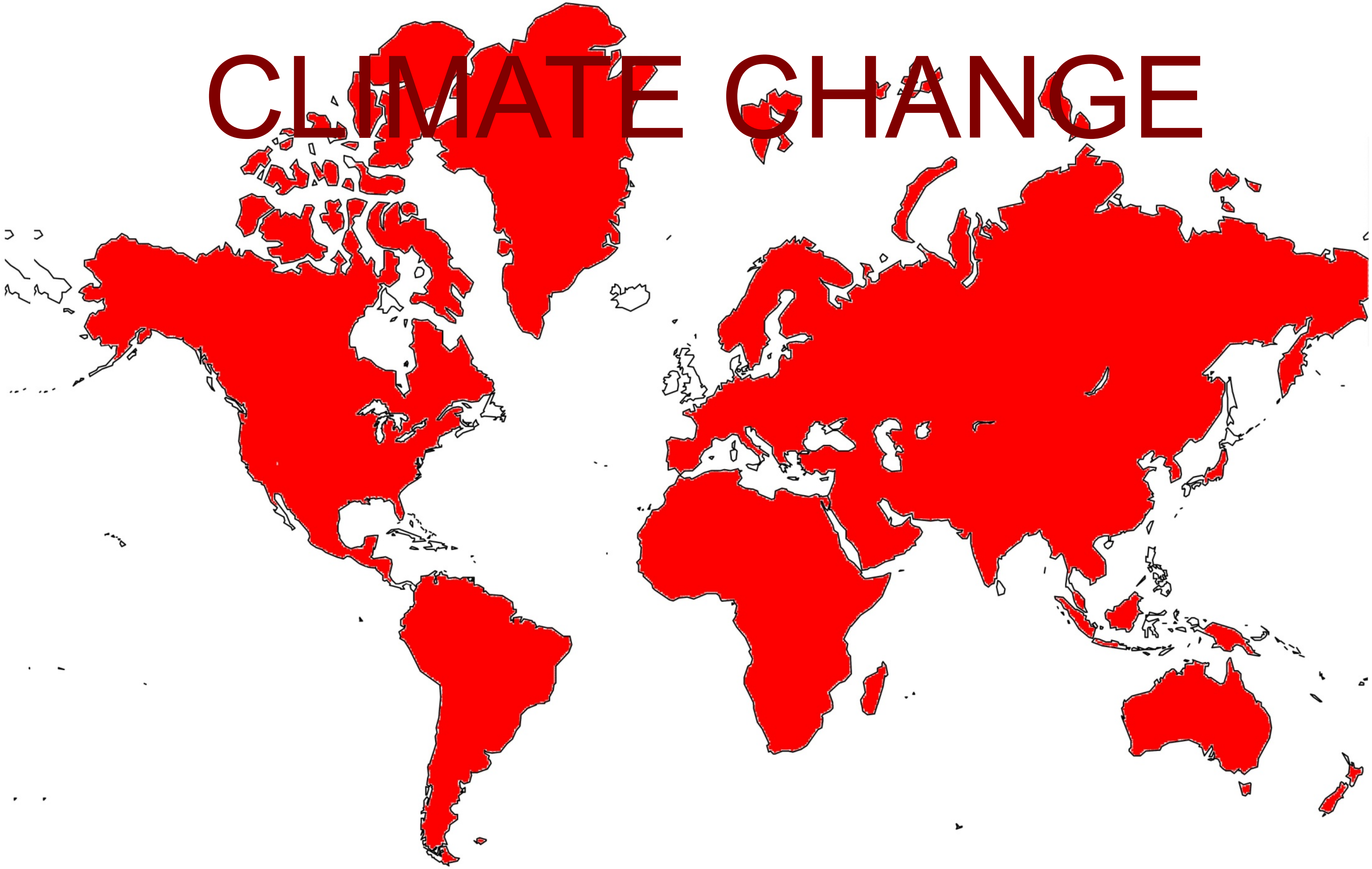
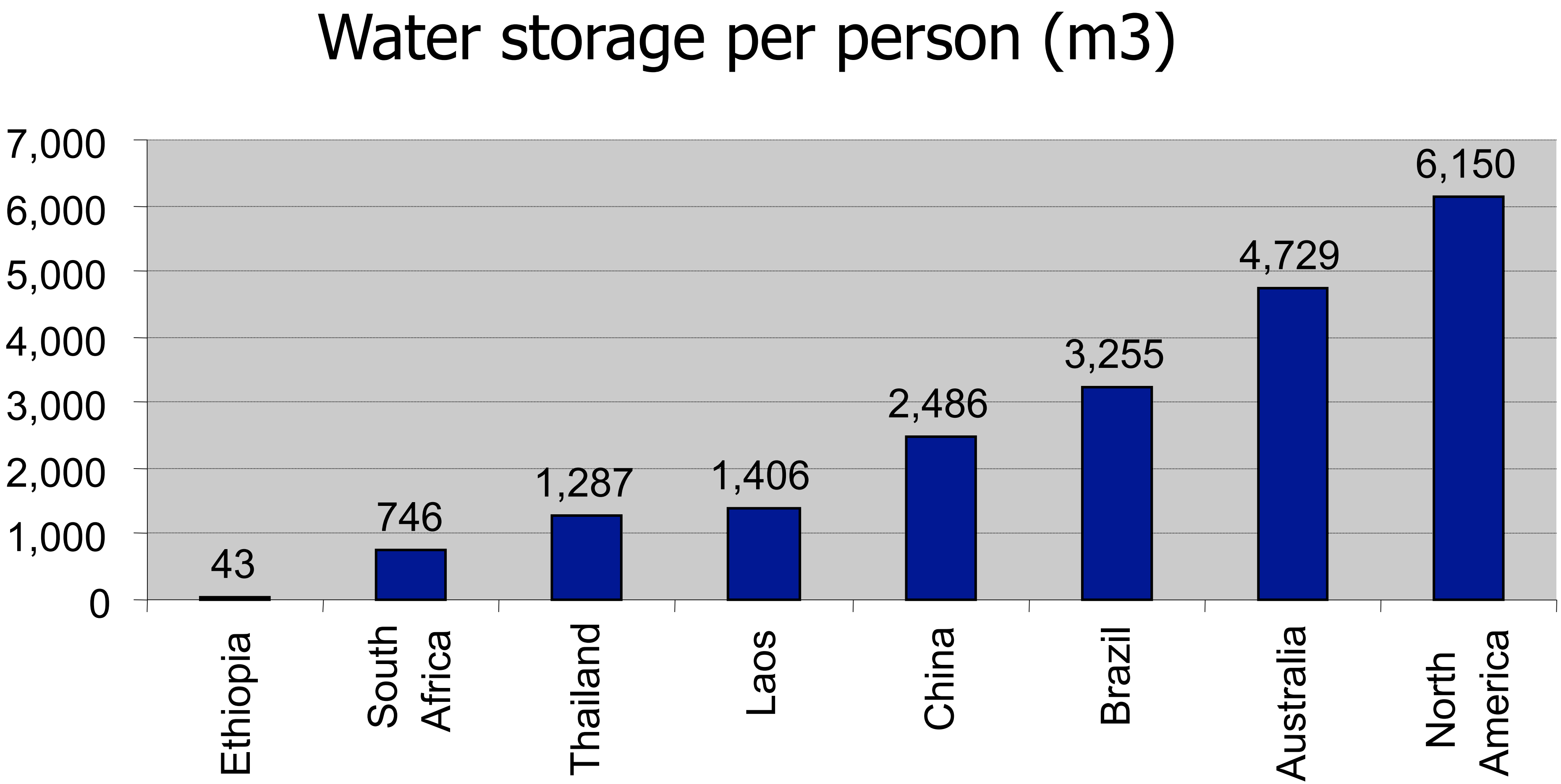
CLIMATE CHANGE



Asymmetries in the Capacity to Control the Resource
Infrastructure gap: Reservoir water storage



Charles J. Vörösmarty

What do we need?

Global information

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Local scale information

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Impact models

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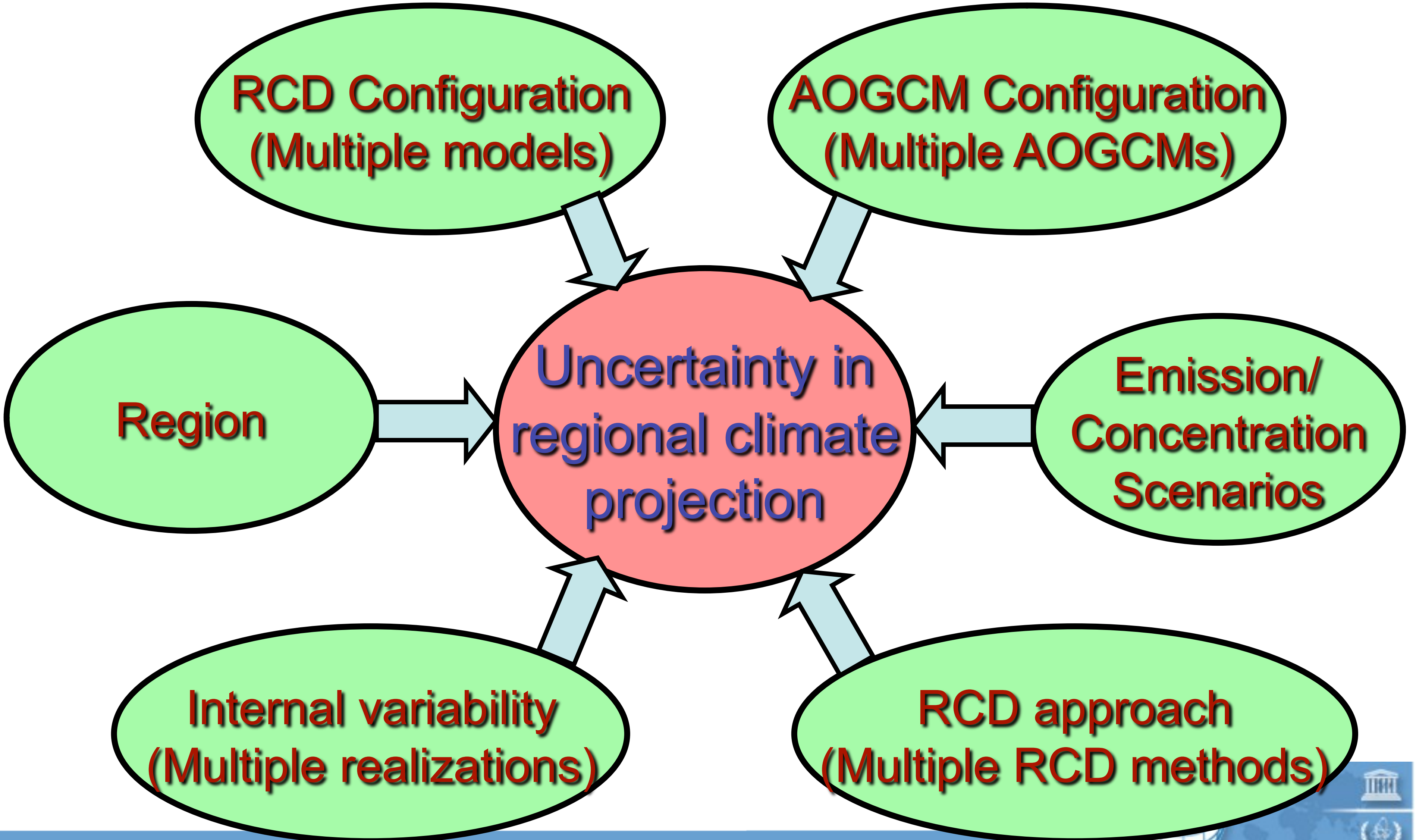
Adaptation and mitigation policies

Sources of uncertainty in RCD-based Regional climate projections



General Aims and Plans for CORDEX

Provide a set of Regional Climate Scenarios for the period 1950-2100, for the majority of the populated land-regions of the globe.

Make these data sets readily available and useable to the impact and adaptation communities.

Provide a generalized framework for testing and applying Regional Climate Models and Downscaling techniques for both the recent past and future scenarios.

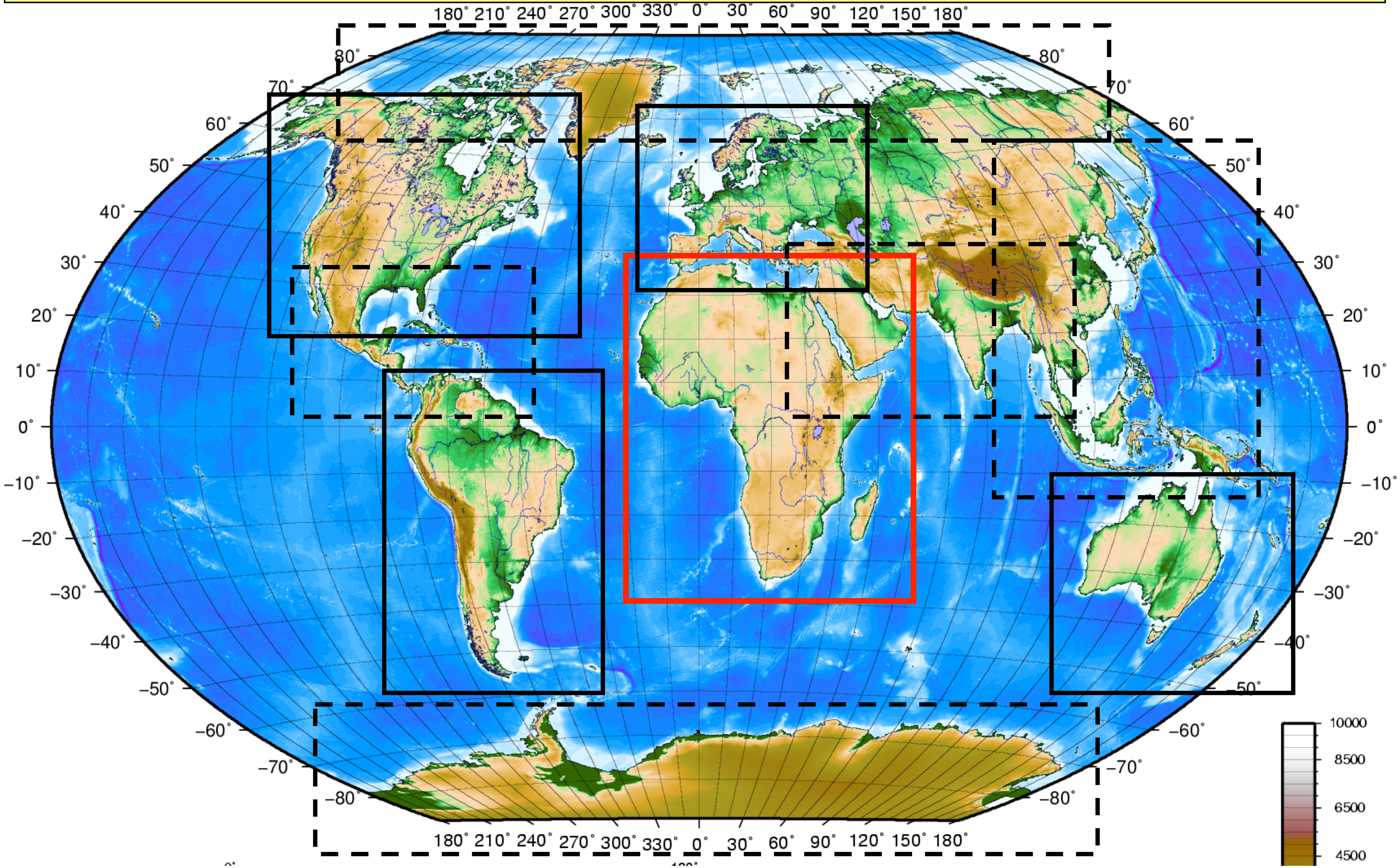
Foster coordination between Regional Downscaling efforts around the world and encourage participation in the downscaling process of local scientists/organizations

Specific aims and plans for CORDEX

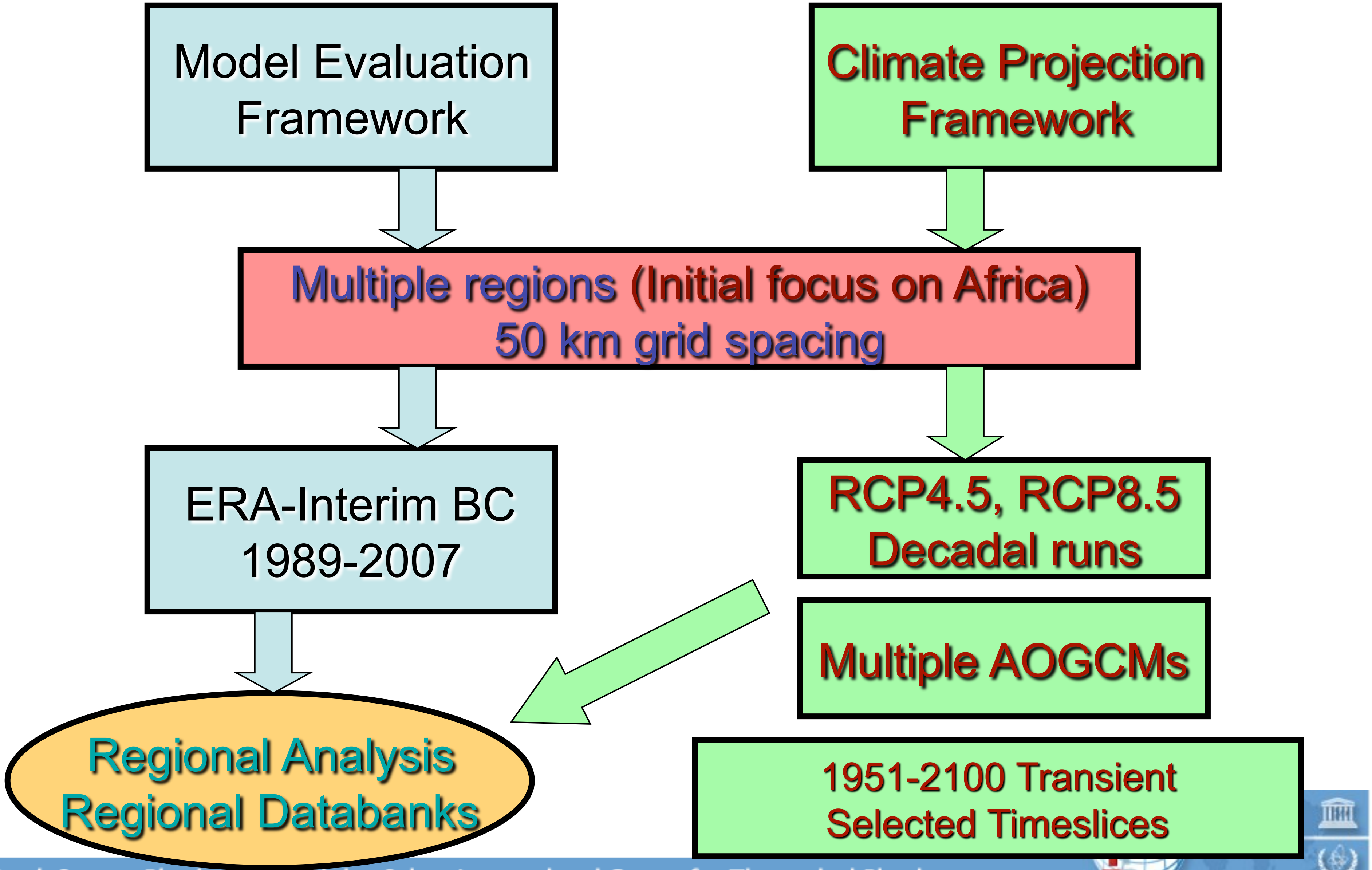
Develop a matrix of RCD simulations that employ:

1. Multiple GCMs as boundary conditions (BCs)
2. Multiple realizations of a given (single) GCM as BCs
3. Multiple RCMs driven by a given GCM over a given domain
4. More than 1 representative greenhouse emission scenario
5. With common RCM domains and resolution
6. With common RCM output variables and frequency
7. In a common format
8. Store the results online for subsequent access and use

Possible CORDEX domains



CORDEX Phase I experiment design

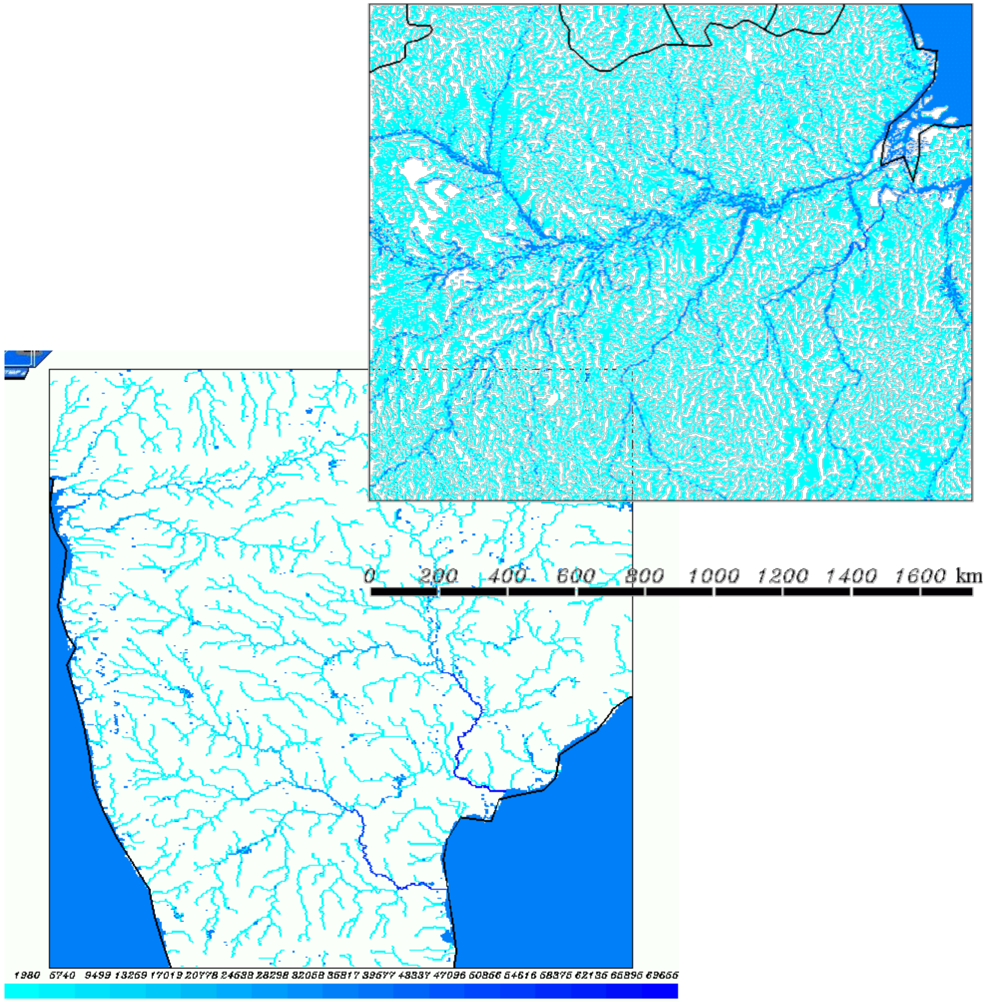


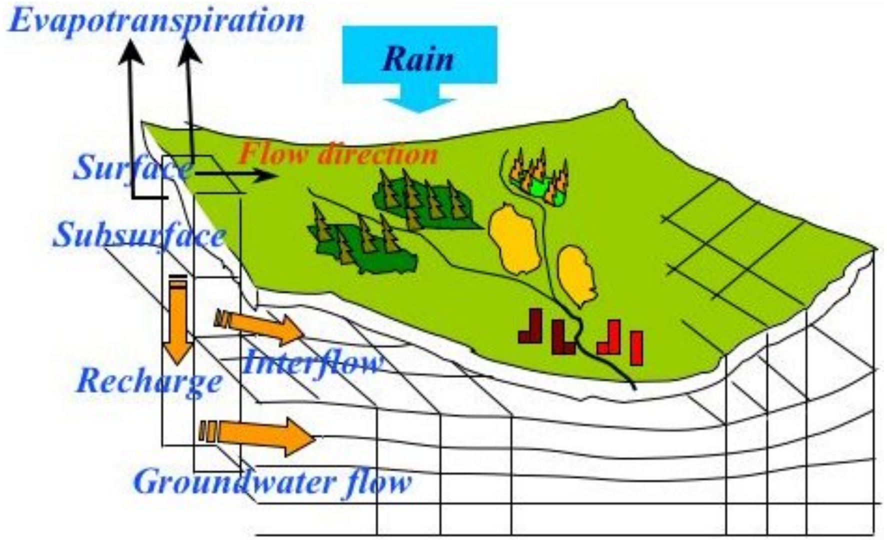
Impact modeling – hydrological modelig

CHyM

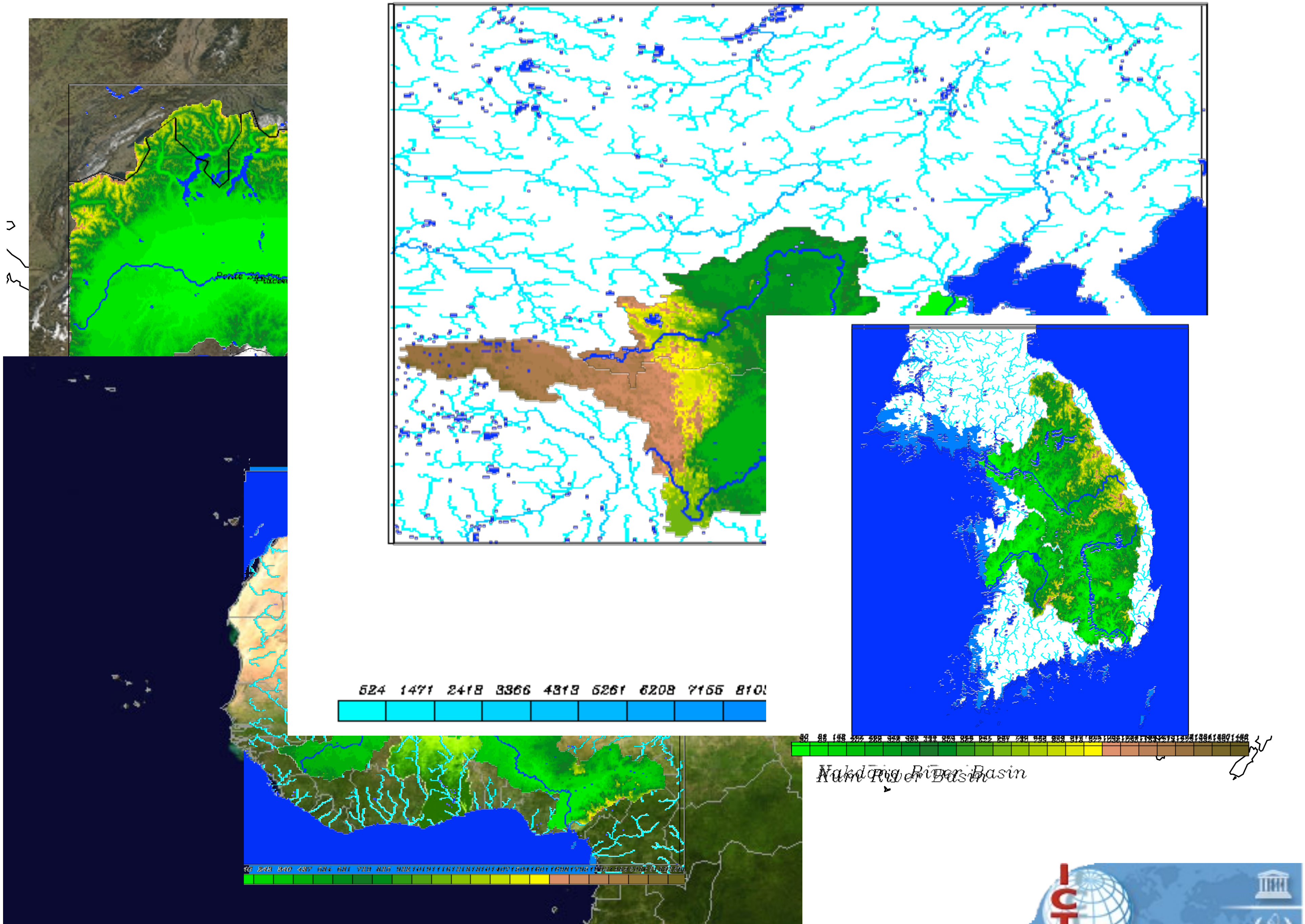
Rain

Runoff
Evapotraspiration
Infiltration





E. Coppola, B. Tomassetti, L. Mariotti, M. Verdecchia and G. Visconti, Cellular automata algorithms for drainage network extraction and rainfall data assimilation, Hydrological Science Journal, 52(3), 2007


524 1471 2418 3366 4313 5261 6208 7165 810
Nakdong River Basin
Kum River Basin

Case studies

Po river (Italy) (1 km resolution; 110945.0 km2 drained area)
5 years RegCM-ERA40 simulation 1995-2000
3 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

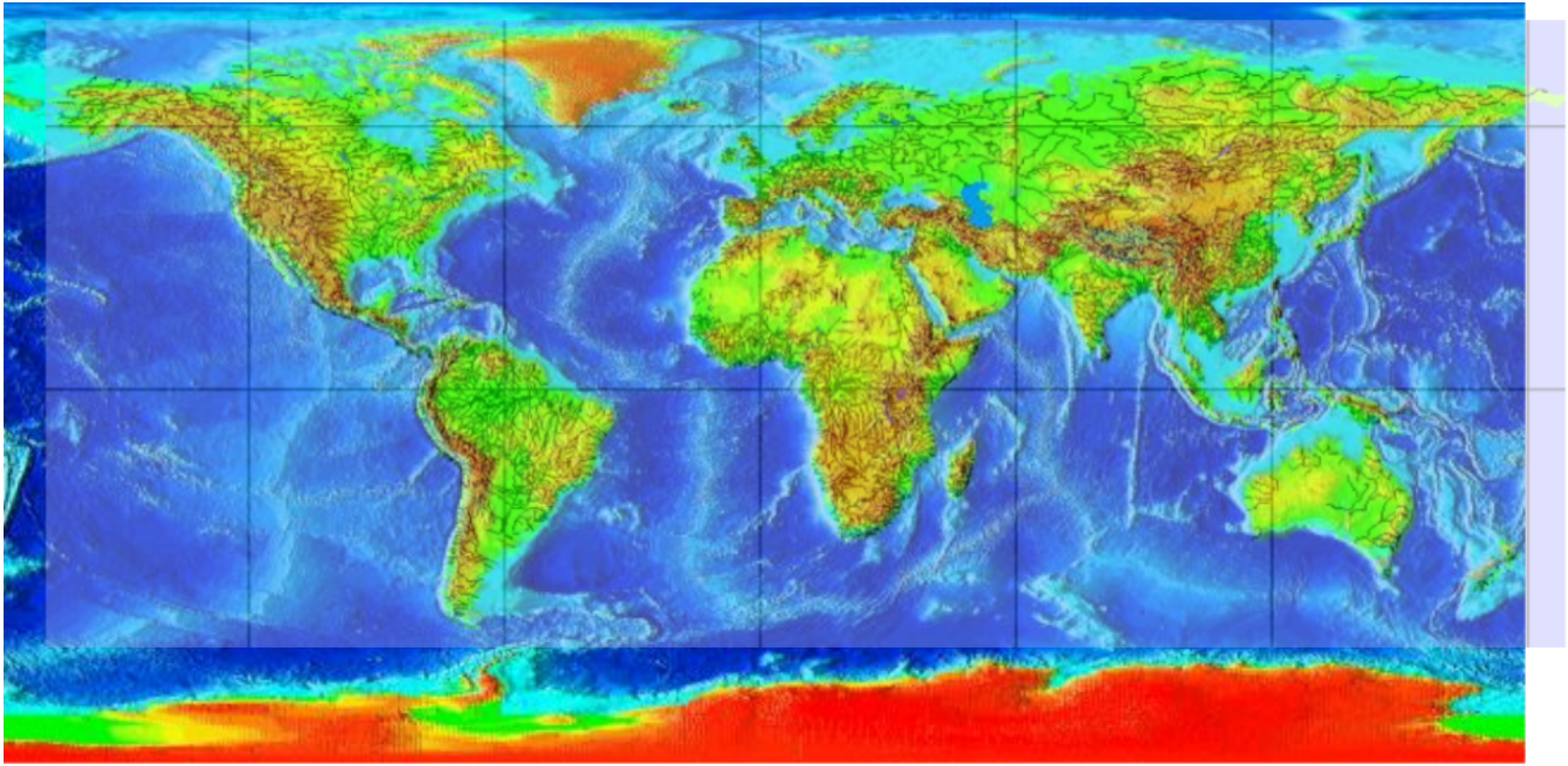
Niger - Volta river (West-Africa)(9.5 km; Niger 2494084 km2,
Volta 434235 km2 drained area)
120 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

Han-Kum-Nakdong river (Korea)(740 m; Han 19678 km2,
Nakdong 15848 km2, Kum 6769 km2 drained area)

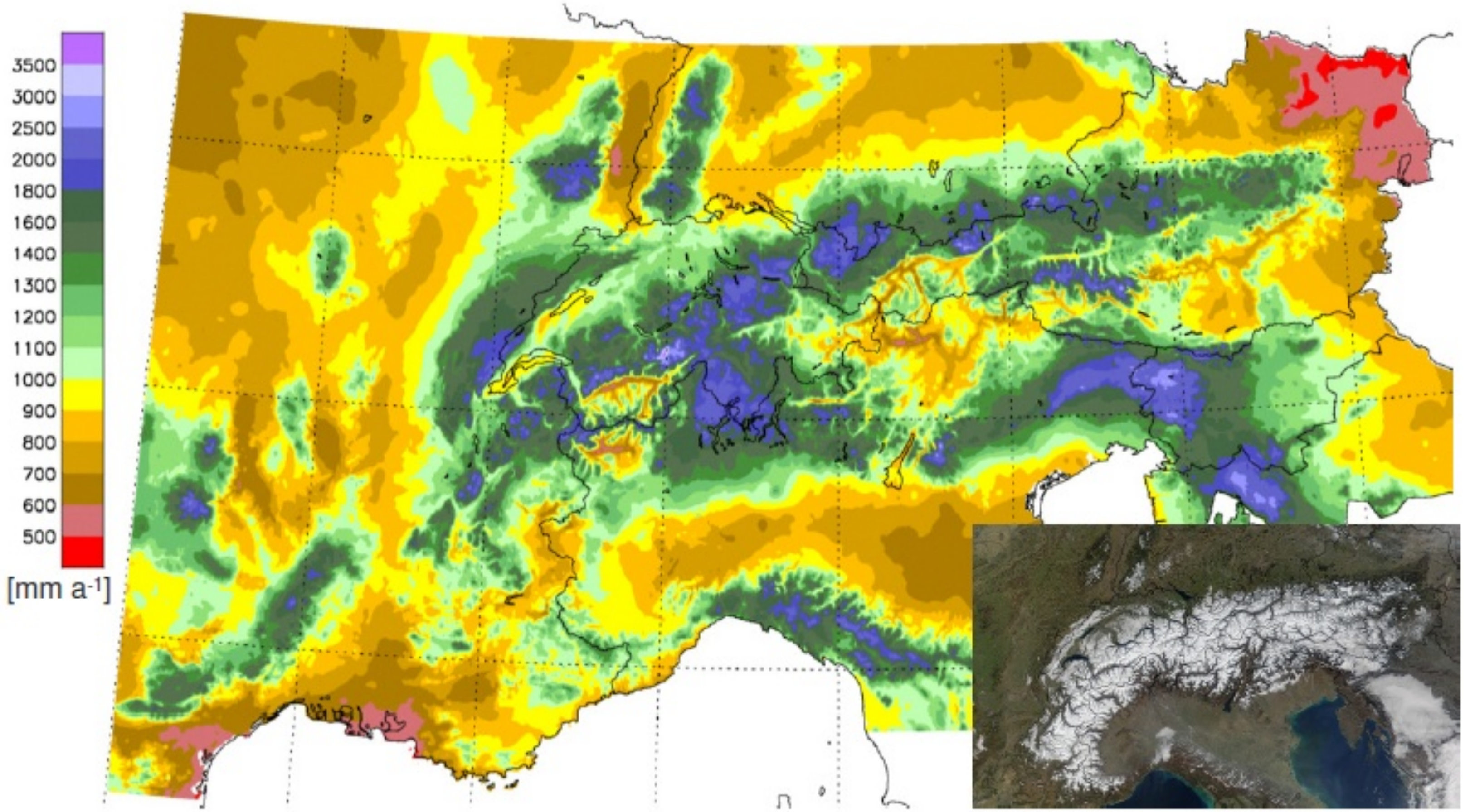
3 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

Yellow – Yangtze river (China)(5.7 km, Yellow river 360431km2,
Yangtze 564594 km2)
1 years RegCM-ECHAM5 A1B scenario simulation 1961- 2071

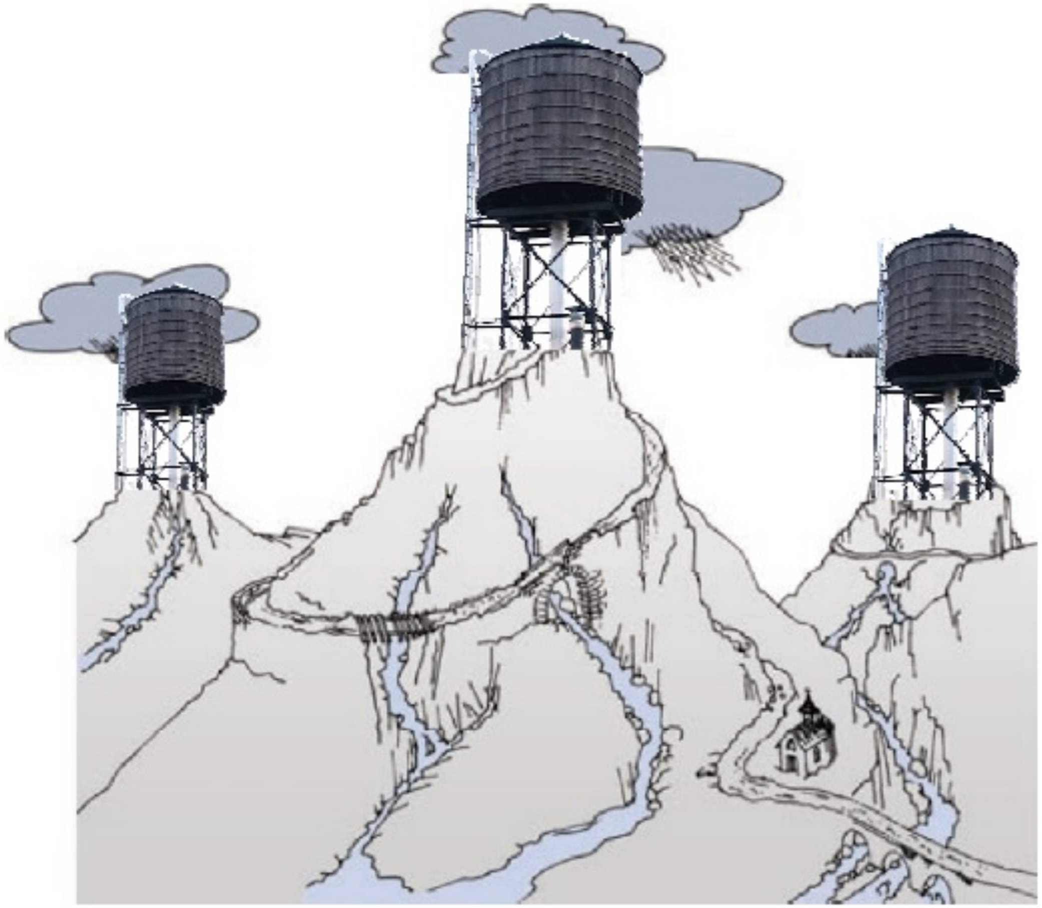
Mountains as a source of more than half the world's rivers



The Alps water tower of Europe



What is a *water tower* ?



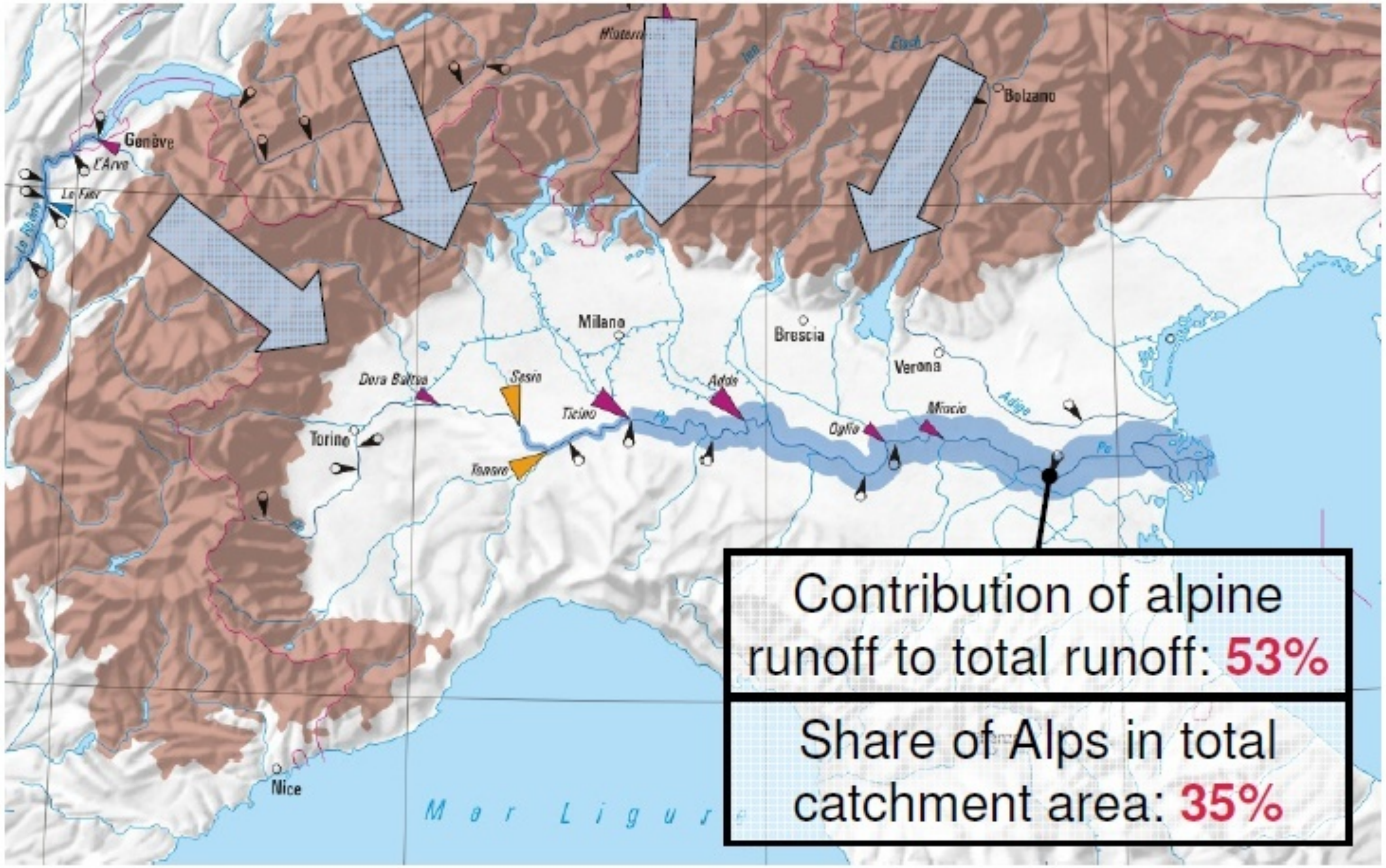
What is a *water tower* ?

> **Superior water supply**
> — higher precipitation
> — lower evapotranspiration

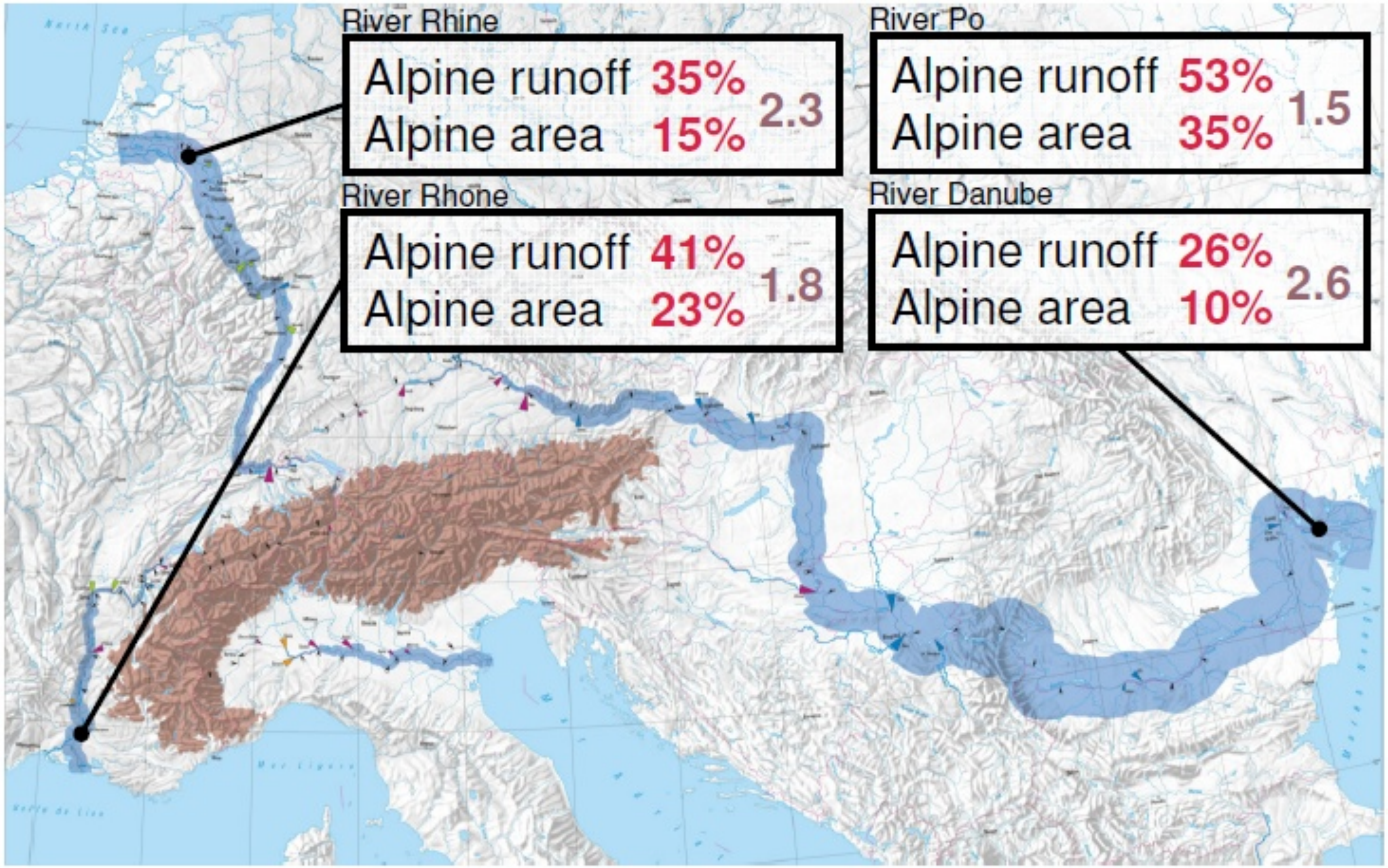
> **Seasonal redistribution of precipitation**
> — snow accumulation in winter
> — snow- and icemelt in spring and summer

> **Highly reliable flows arrive just in time**
> — highly dependable flows from snow- and icemelt
> — attenuation of downstream water deficits in summer

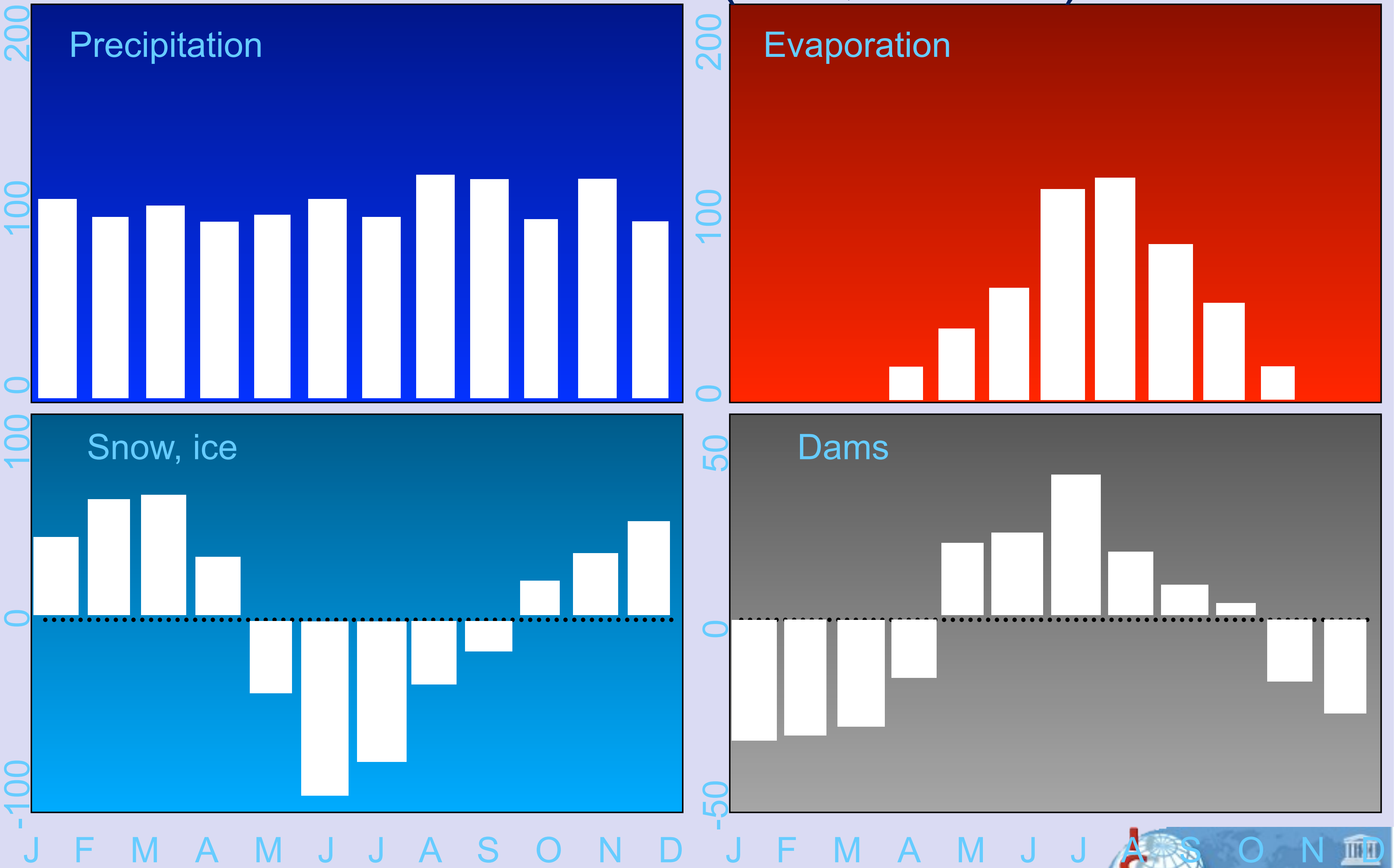
The Alps water tower of Europe the river Po



The Alps water tower of Europe: the 4 major rivers

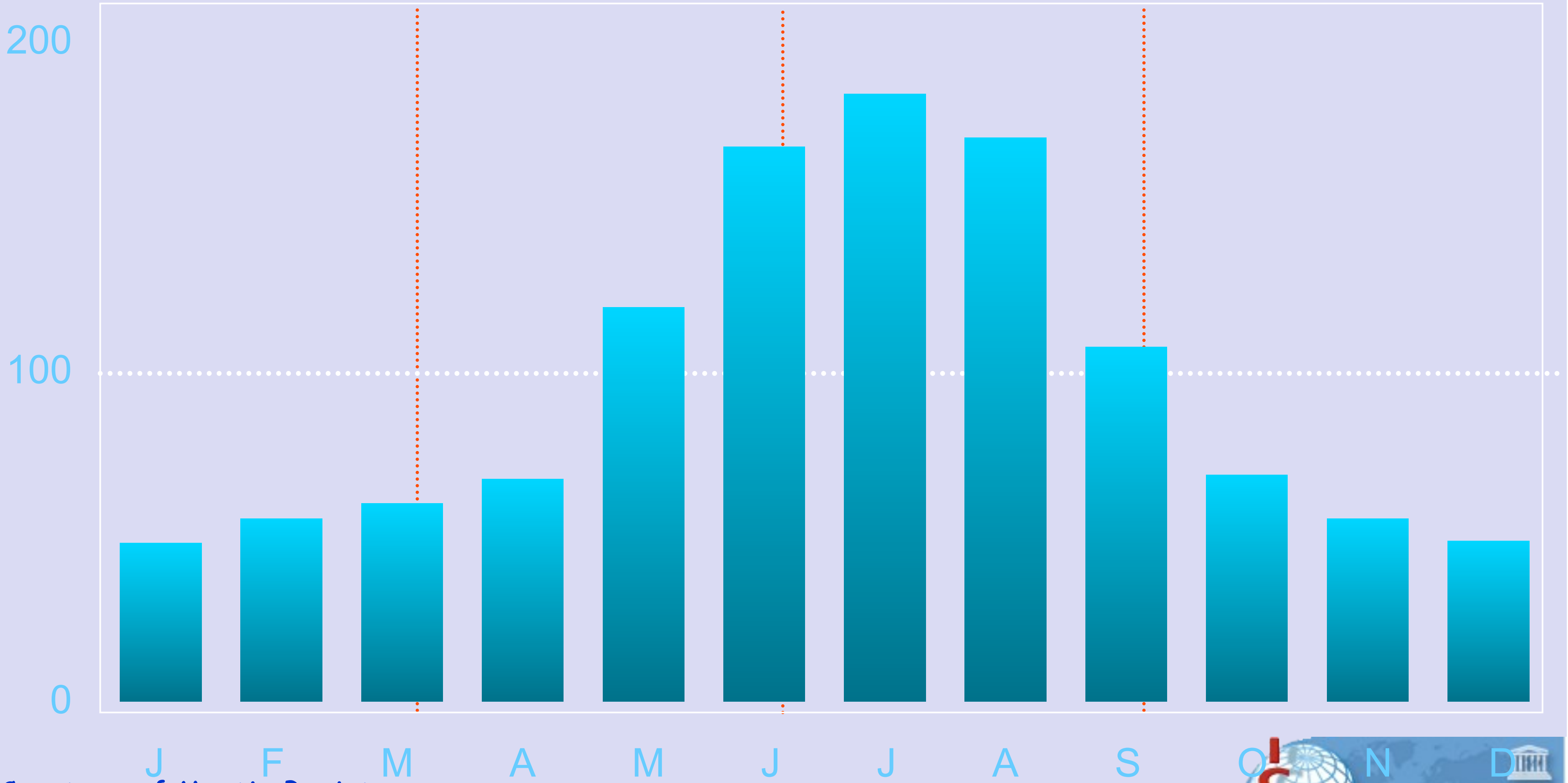


Components of the hydrological cycle under current climate (mm, Rhone)



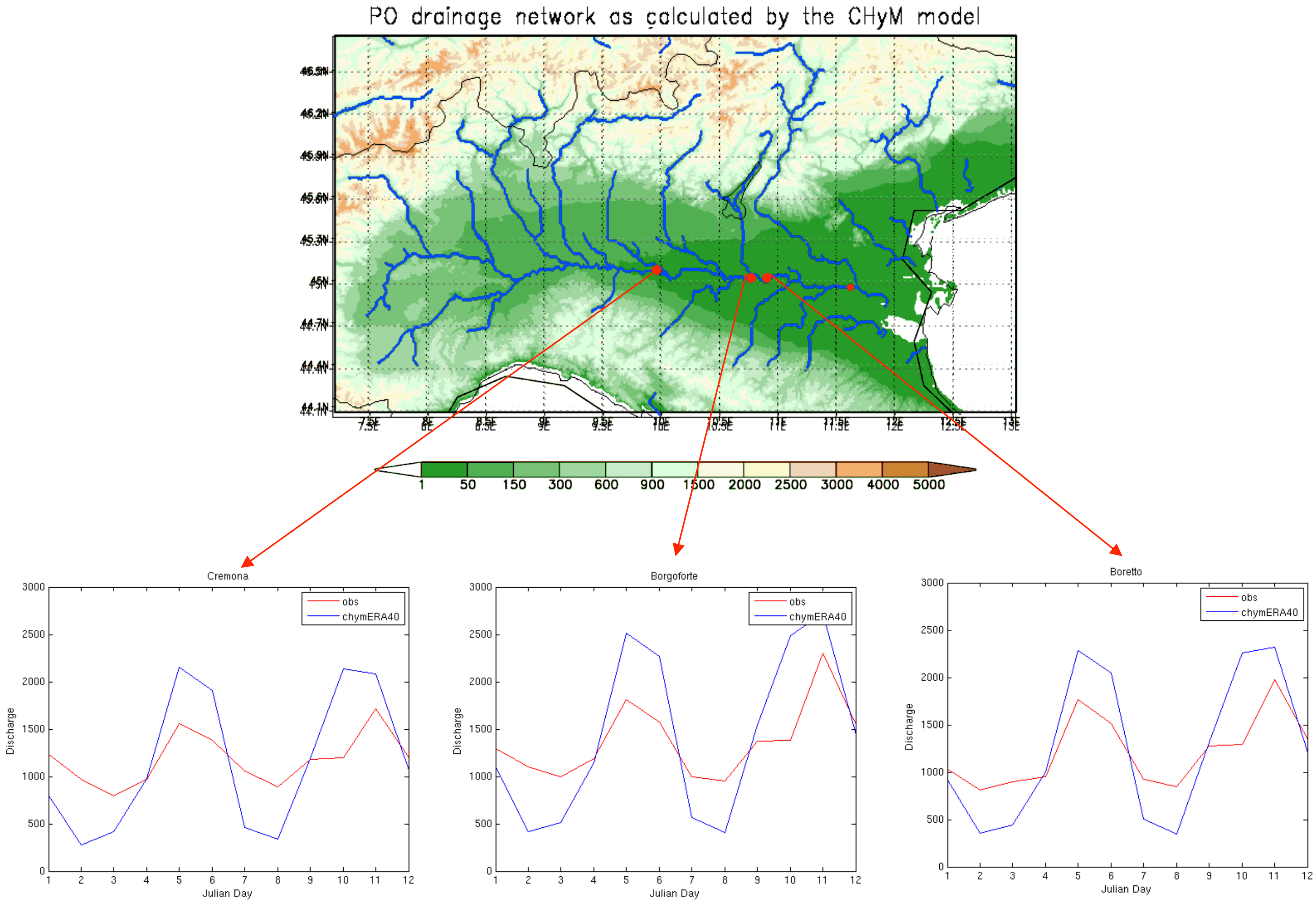
Courtesy of Martin Beniston

Average monthly discharge (mm, Rhone)



Courtesy of Martin Beniston

Average monthly discharge (mm, Po)



Avg. discharge1540 m³/s

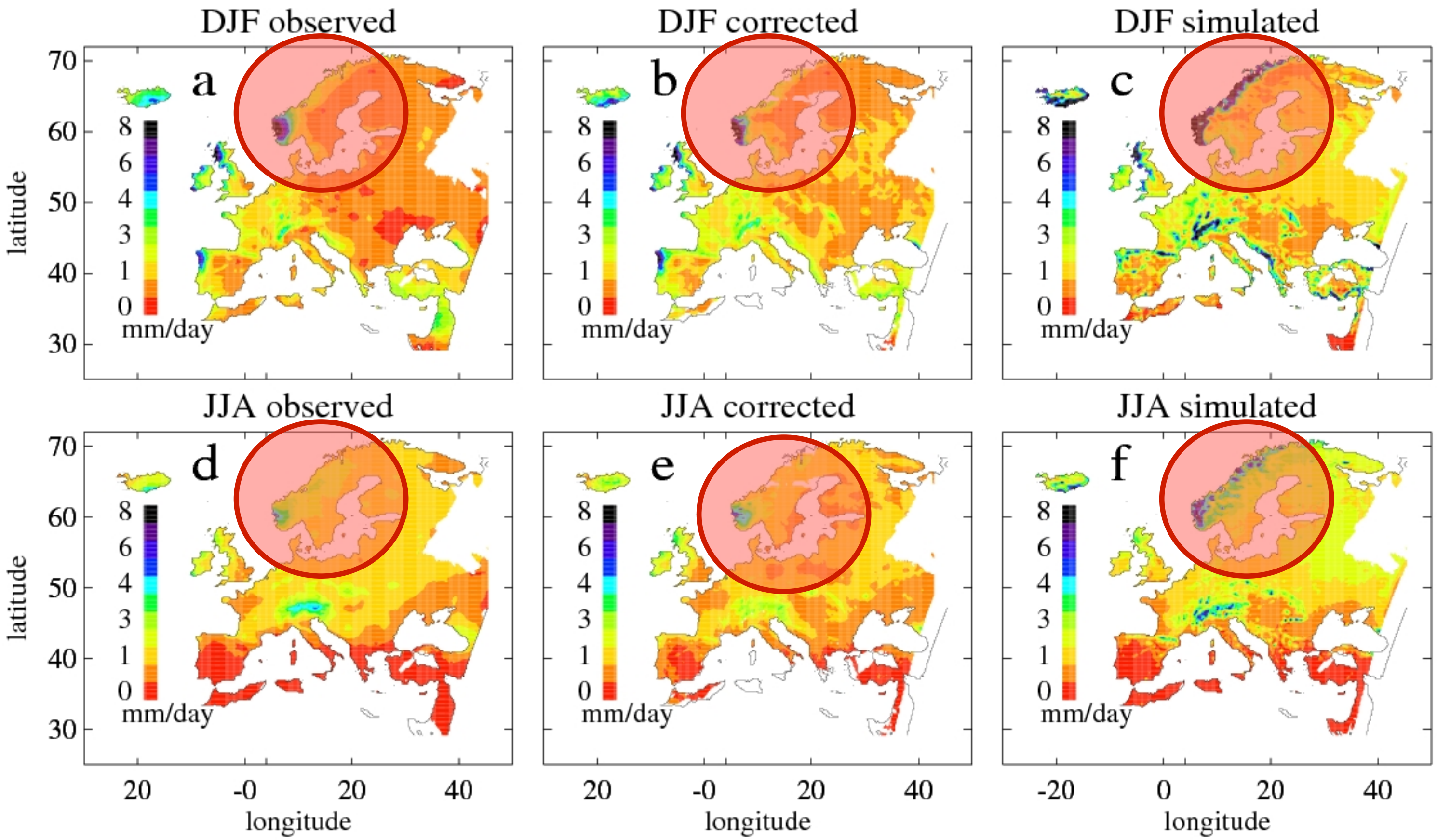
Bias correction

All aspects of the field statistics need to be corrected (frequency, mean, variability).

Bias correction needs to be robust:

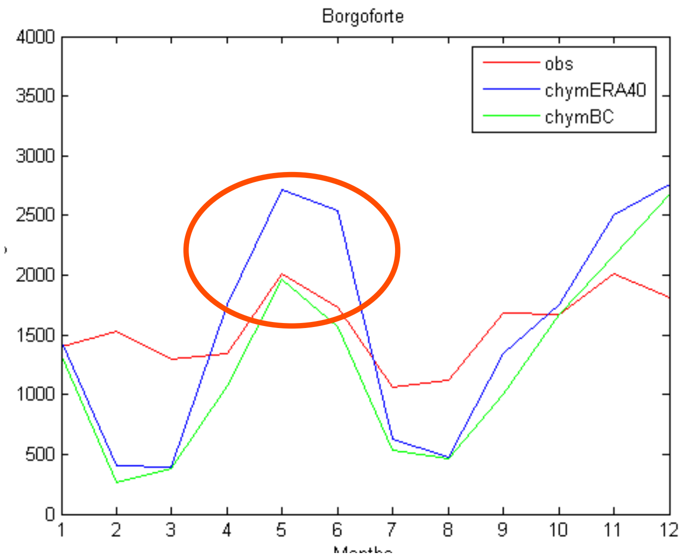
- Constant in time.
- Few parameters (many degrees of freedom…)

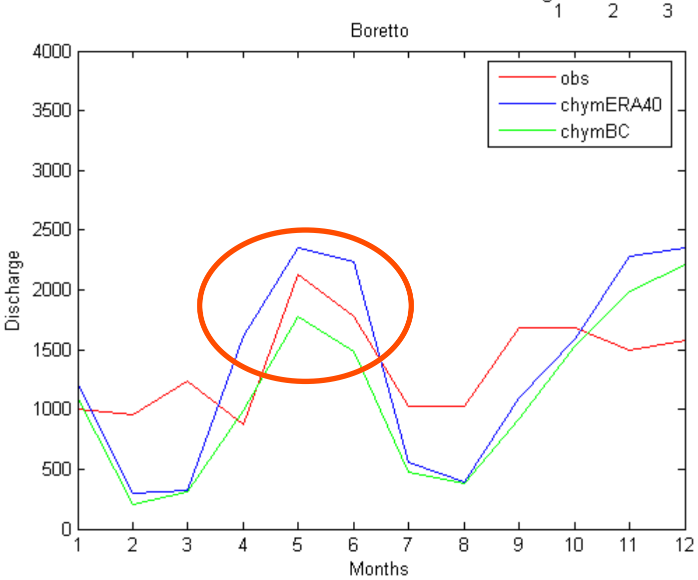
Seasonal mean

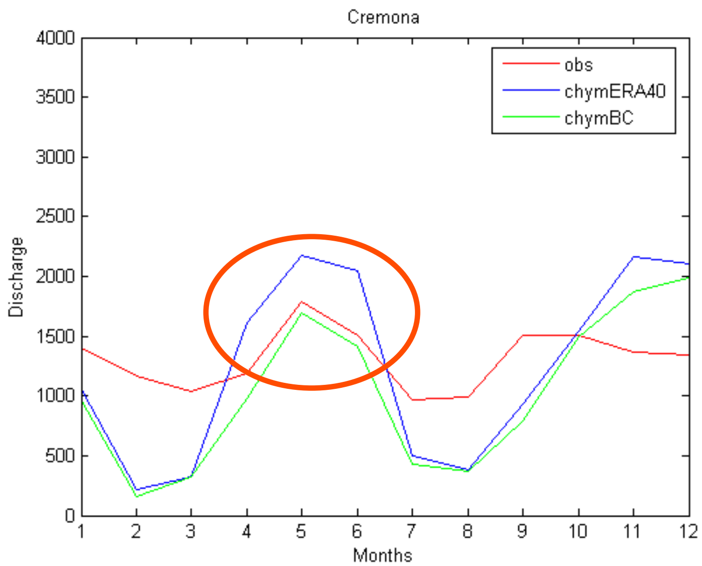


C. Piani, J.O. Haerter, **E. Coppola** (2009): Testing a statistical bias correction method for daily precipitation in regional models over Europe, Theoretical and Applied Climatology

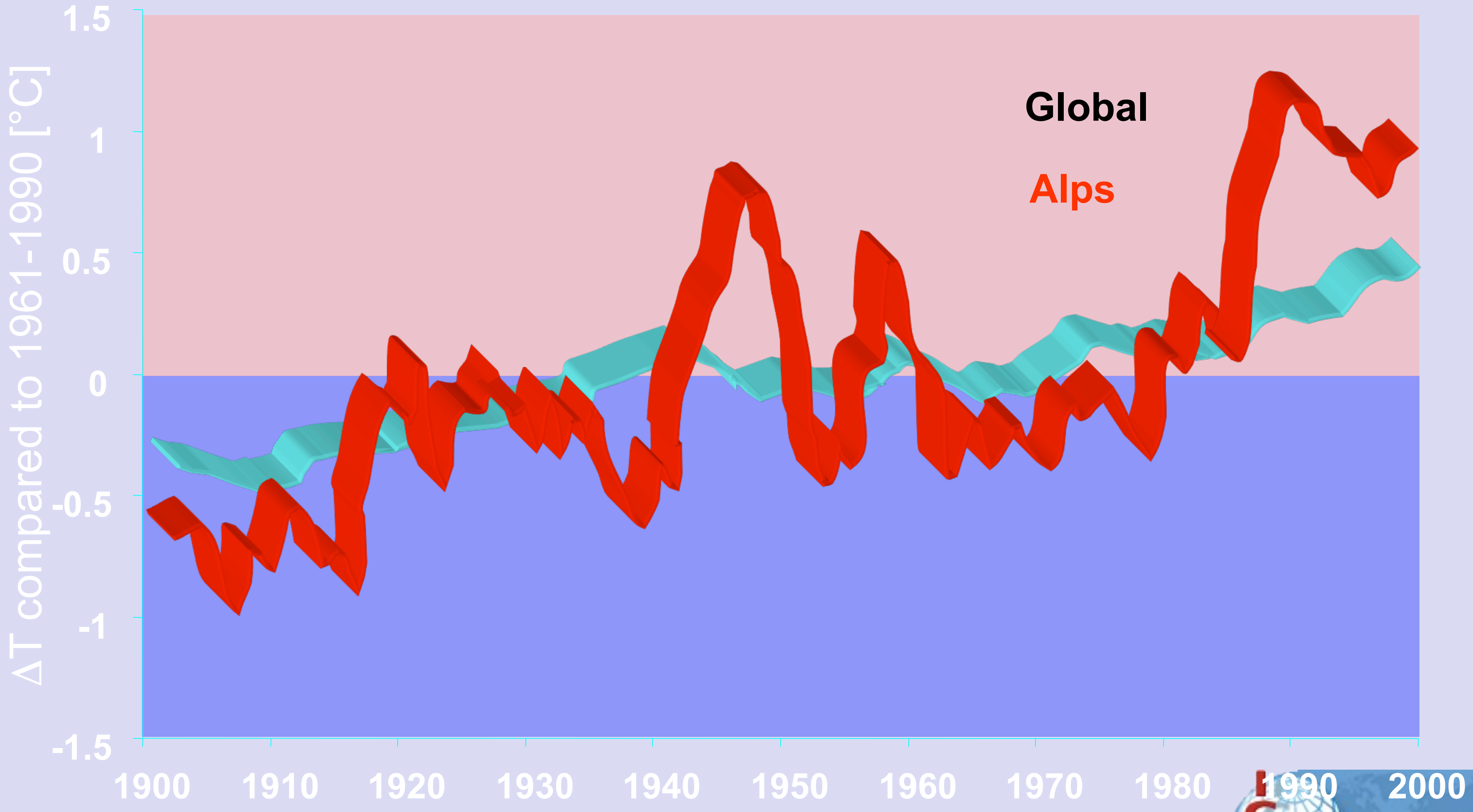
Discarge after bias correcting (two years only)





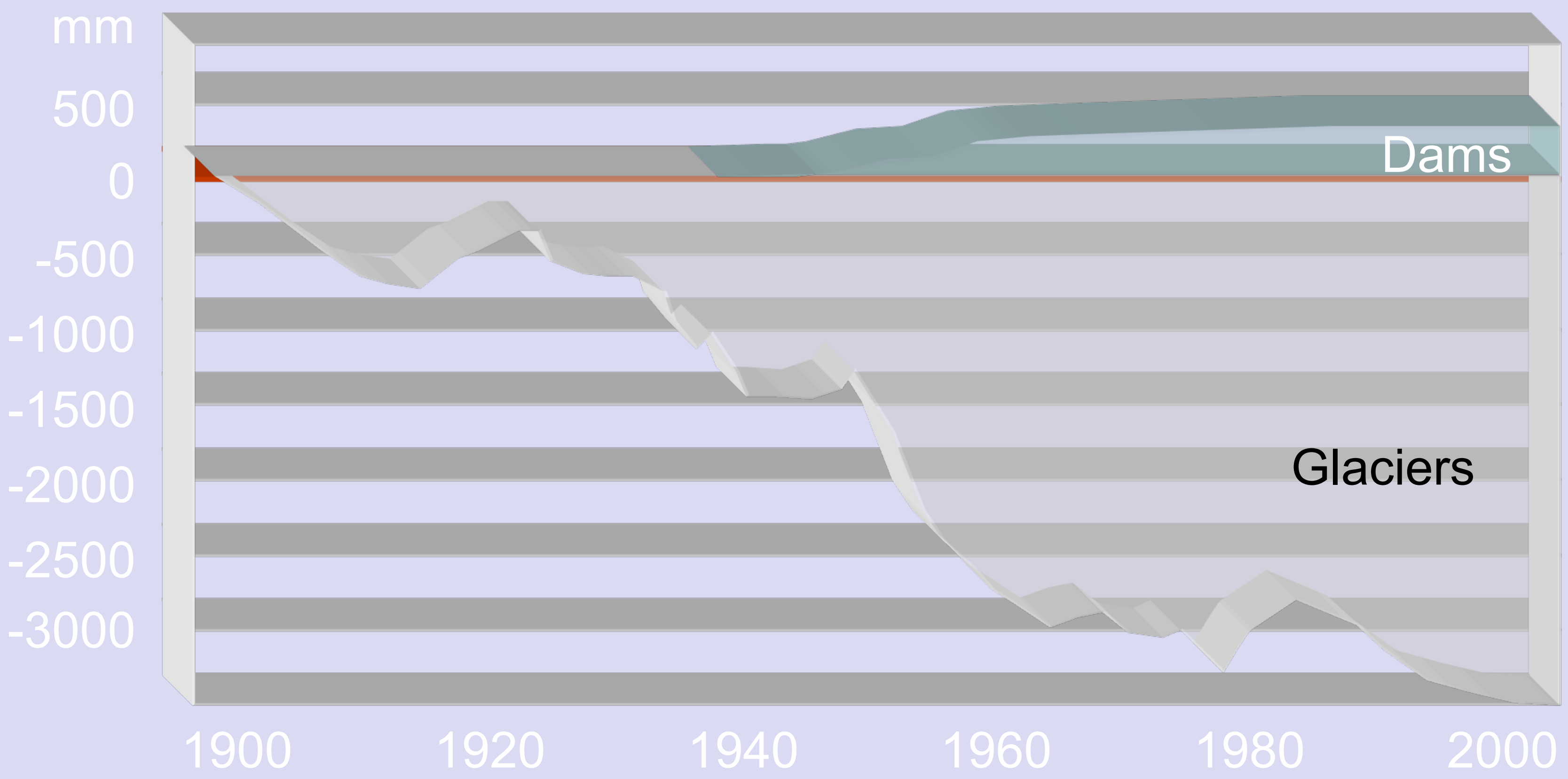


Evolution of global and alpine temperatures, 1901-2000



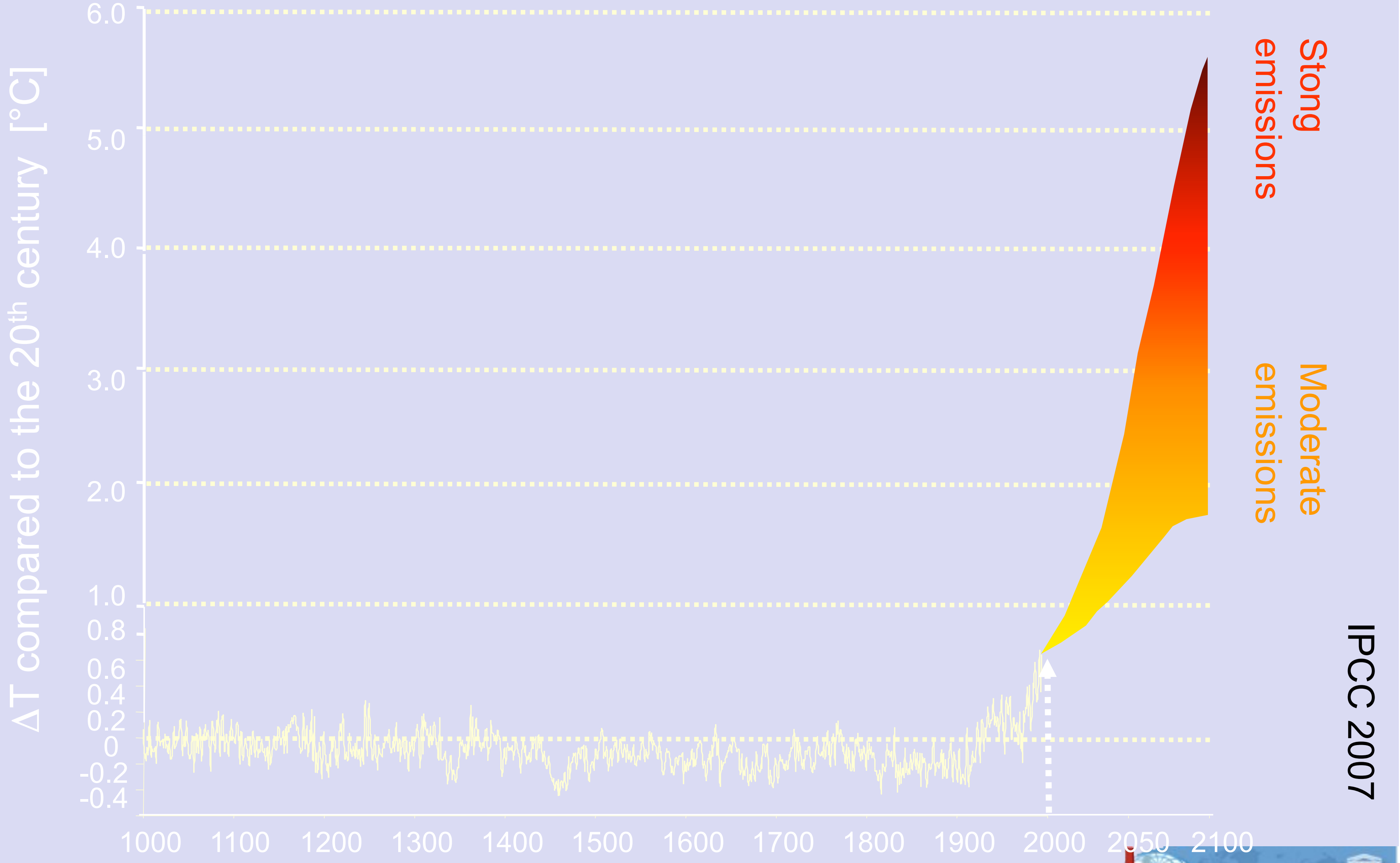
Beniston, 2000: Environmental Change in Mountains, Arnold, London

Changes in water availability for the Rhône River

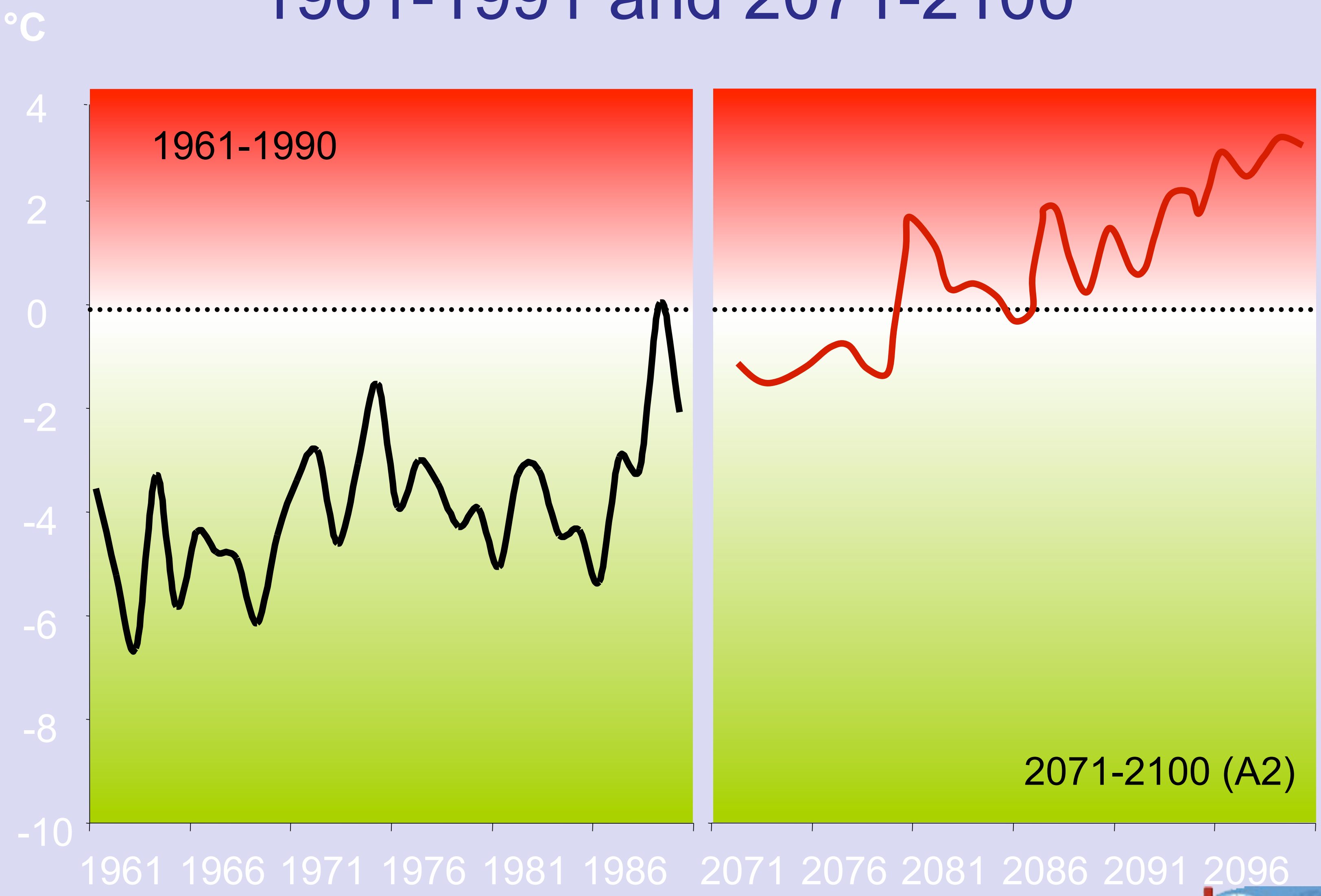


Courtesy of Martin Beniston

Climate futures



Winter temperatures at Säntis (2,500 m): 1961-1991 and 2071-2100



Beniston, 2004: Climatic Change and Impacts, Springer Publishers

Global

CMIP3 model – country-resolution	20C	B1	A1B	A2
BCCR–Norway(1.9°)	1			1
CGCM-Canada(2.8°–1.9°)	6	4	4	2
CNRM-CM3-France(1.9°)	1	1	1	1
CSIRO-MK-Australia(1.9°)	2	1	1	1
GFDL–CM2.0-USA(2° × 2.5°)	3		1	1
GFDL-CM2.1-USA(2° × 2.5°)	3	1	1	1
GISS-AOM-USA(3° × 4°)	1		2	1
GISS-EH-USA(4° × 5°)	5	1	1	
INMCM-Russia(4° × 5°)	1	1	1	1
IPSL-CM4-France(2.5° × 3.75°)	1	1	1	1
MIROCH-Japan(1.1°)	1		1	
MIROCM-Japan(2.8°)	3	3	3	3
ECHO-G-Germany/Korea(3.9°)	5	3	3	3
ECHAM5/MPI-Germany(1.9°)	3	3	2	3
MRI-CGCM-Japan(2.8°)	5	5	5	5
NCAR-CCSM3 – USA(1.4°)	8	8	6	4
NCAR-PCM-USA(2.8°)	4	2	3	4
UKMO-HadCM3-UK(2.5° × 3.75°)	1	1	1	1
UKMO-HadGEM-UK(1.3° × 1.9°)	1		1	

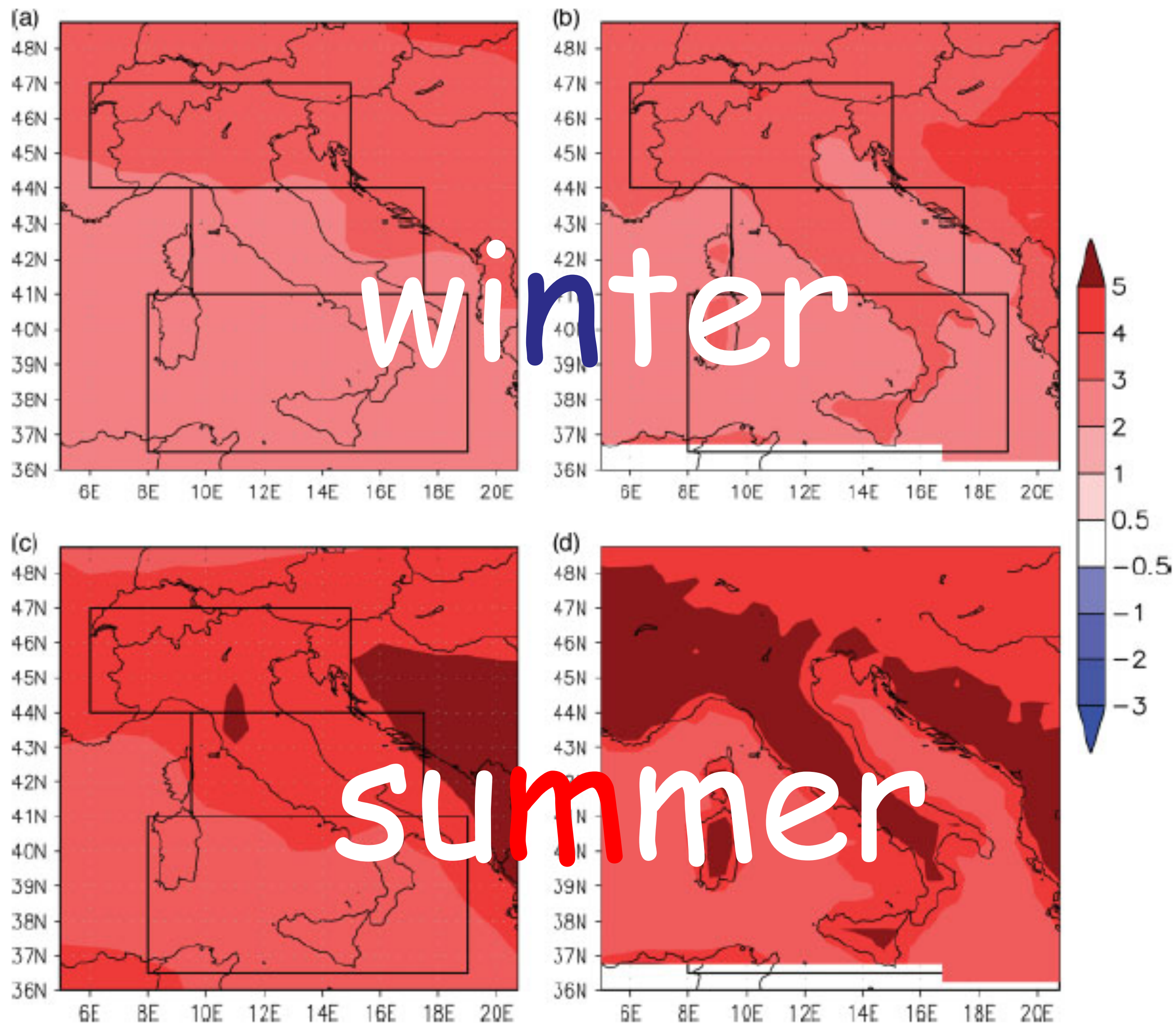
19 models

Regional

PRUDENCE model-institute	20C	B2	A2
DMI-HIRHAM(HadAM3H/ECHAM4)	8	2	7
ETH -CHRM (HadAM3H)	1		1
GKSS -CLM (HadAM3H)	2		2
HC -HadCM3 (HadAM3H)	3	1	3
ICTP -RegCM (HadAM3H)	1	1	1
KNMI -RACMO (HadAM3H)	1		1
CNRM -Arpège (Arpege/HadCM3H)	3	4	4
MPI -REMO (HadAM3H)	1		1
SMHI-RCAO (HadAM3H/ECHAM4)	3	2	4
UCM -PROMES (HadAM3H)	1	1	1

10 models

Global Regional

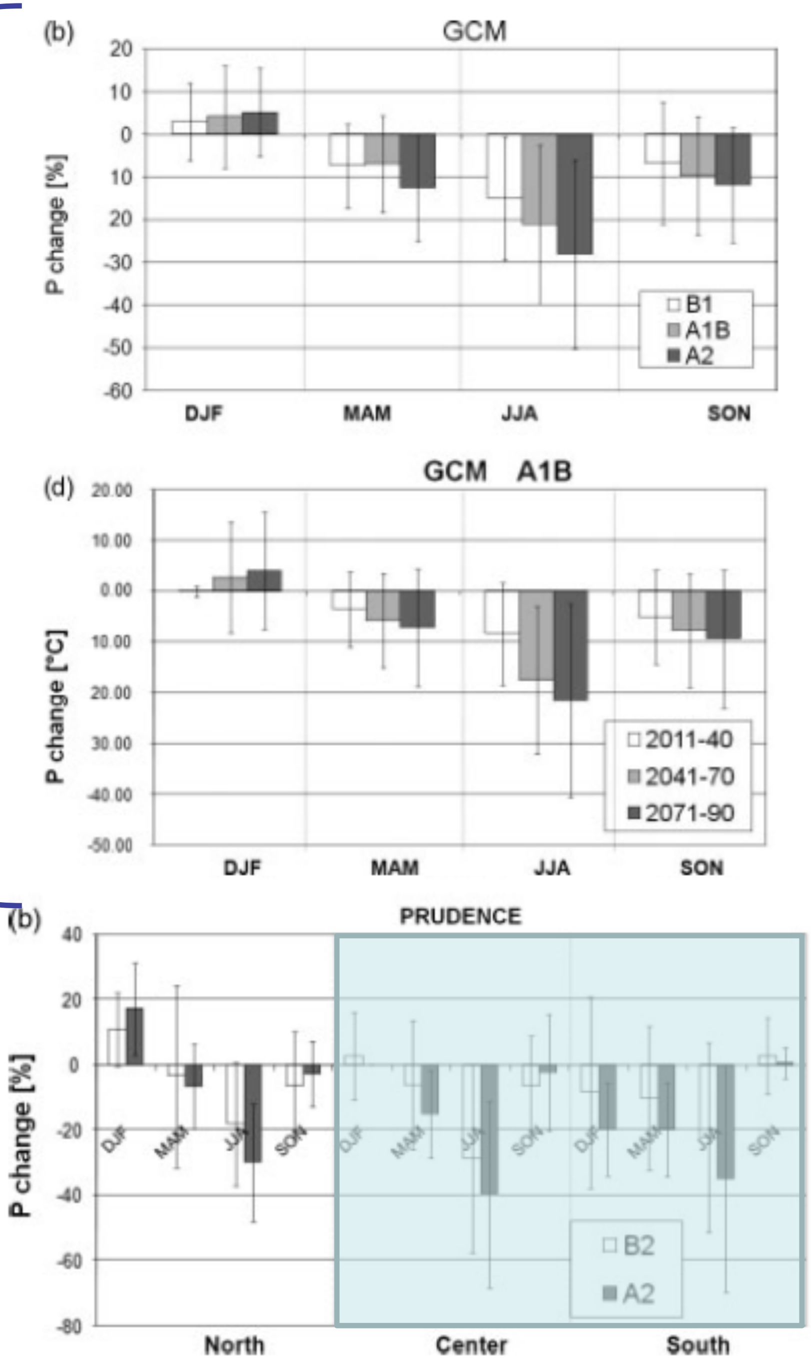


Ensemble average surface air temperature and precipitation change (A2 scenario, 2071 2100 minus 1961 1990)

Coppola E. and Giorgi F., 2010

Global

Regional



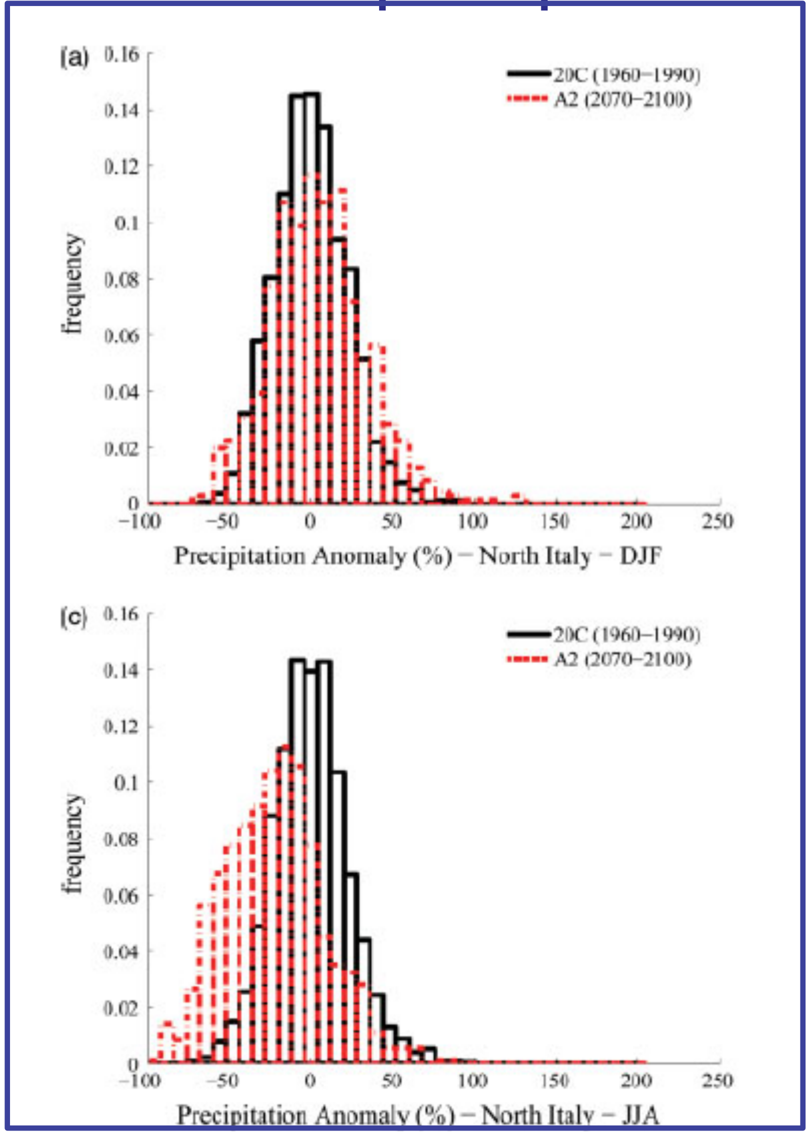
Ensemble average precipitation [%] changes over the Alps region. For each mean change value the corresponding inter-model standard deviation of the changes is reported

Coppola E. and Giorgi F., 2010

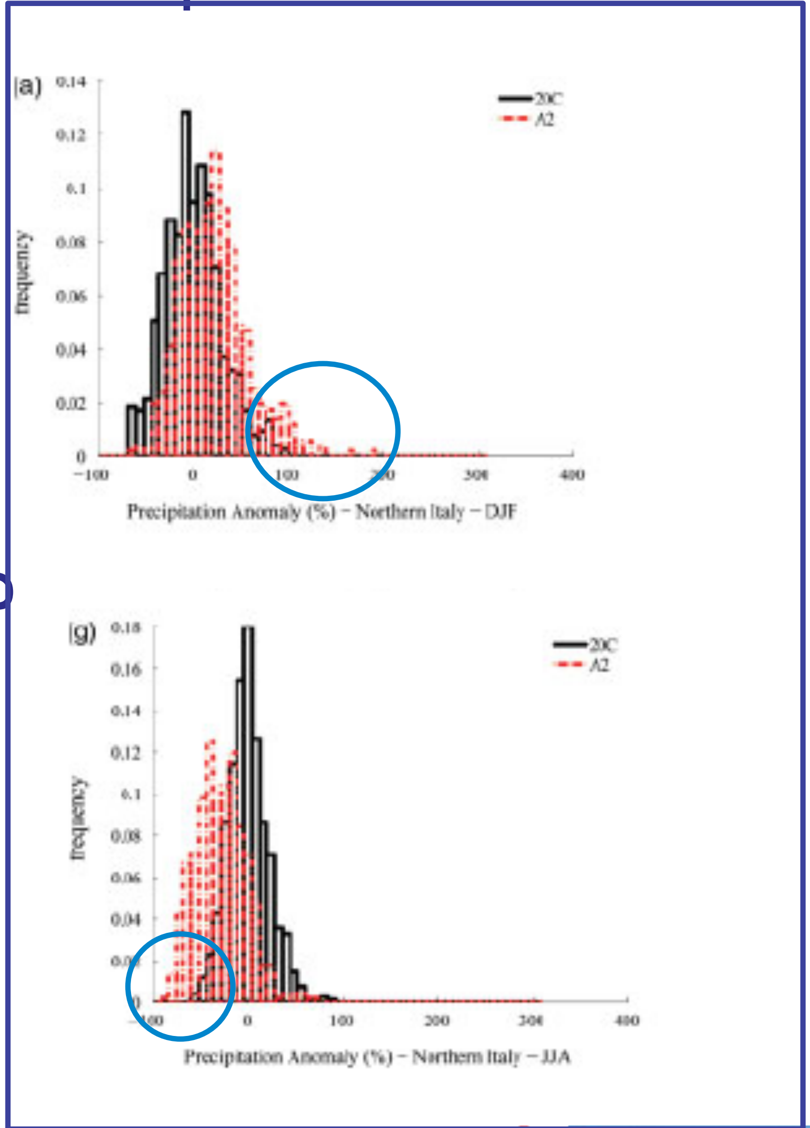
Coppola E. and Giorgi F., 2010,

Changes in extreme precipitation in the Alps

Global

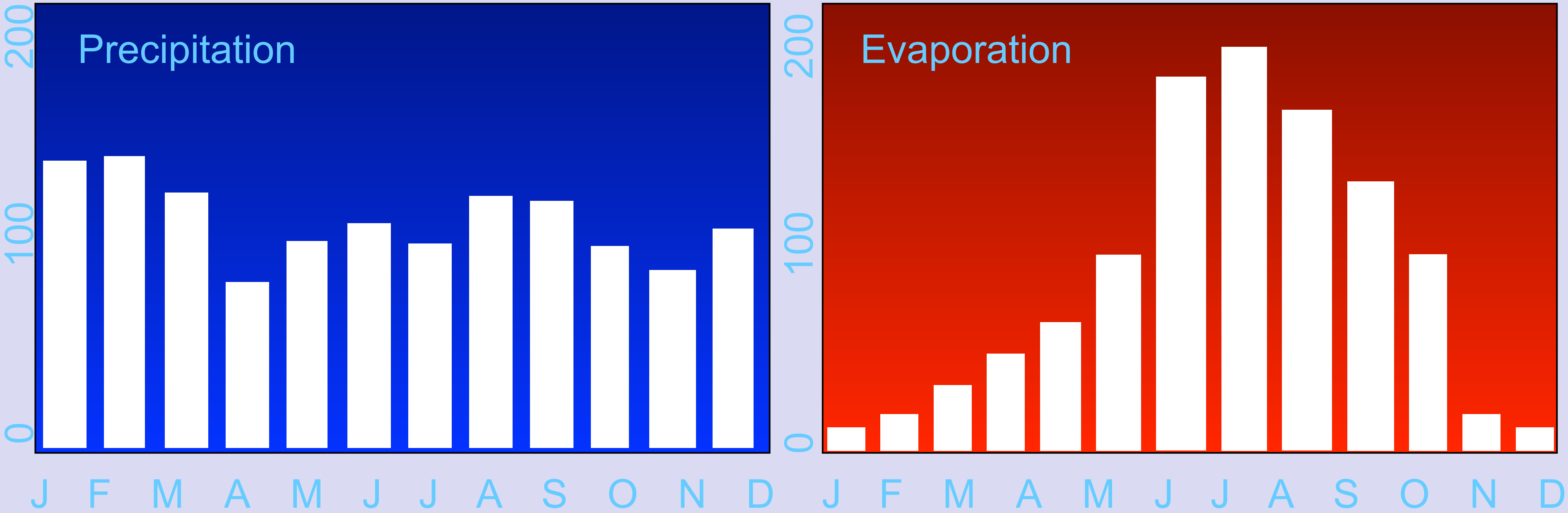


Regional



Increase in both extreme dry (drought prone) and wet (flood prone) seasons

Components of the hydrological cycle by 2100 (mm, Rhone)



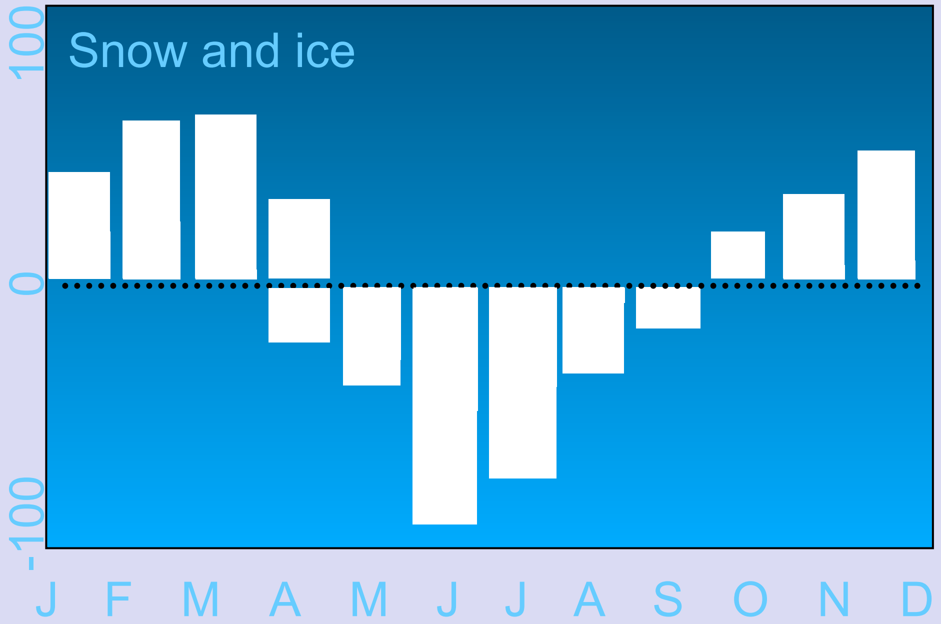
Courtesy of Martin Beniston

Glacier retreat: Italian Alps

Glacier retreat: Tschierva Glacier, Engadine

Courtesy: Max Maisch
University of Zurich, Switzerland

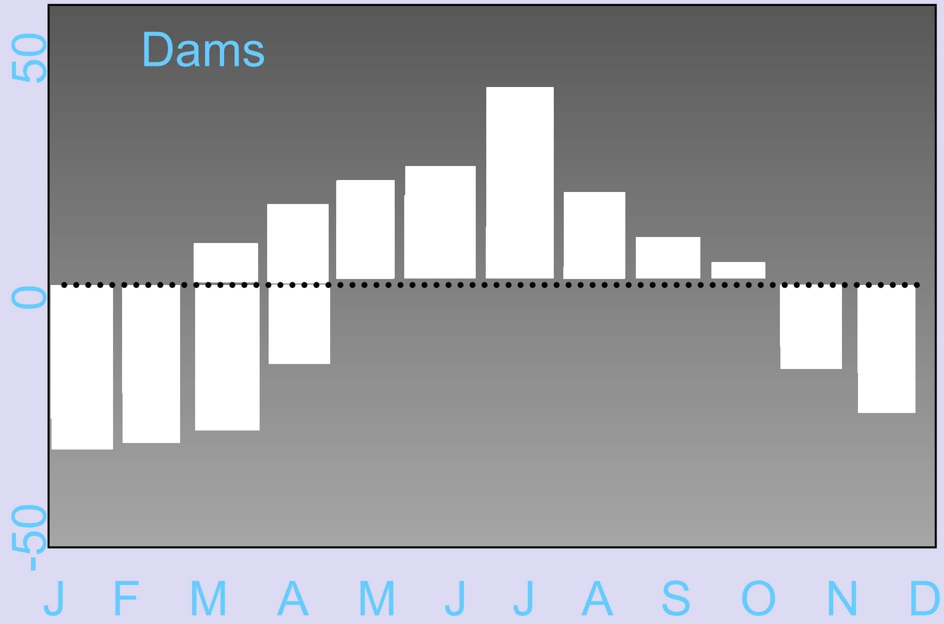
Components of the hydrological cycle by 2100 (mm, Rhone)



Courtesy of Martin Beniston

Grande Dixence, Switzerland

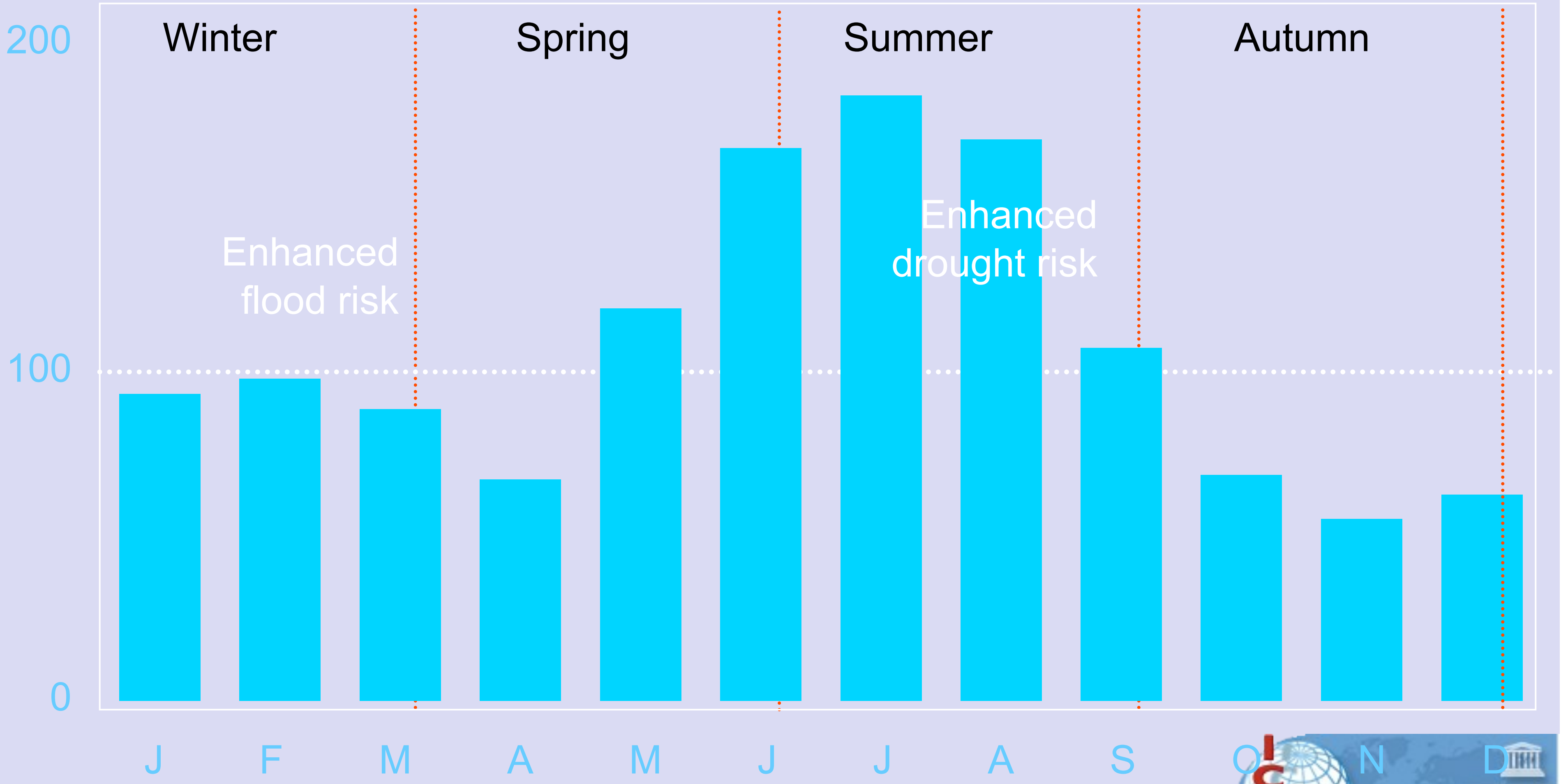
Components of the hydrological cycle by 2100 (mm, Rhone)



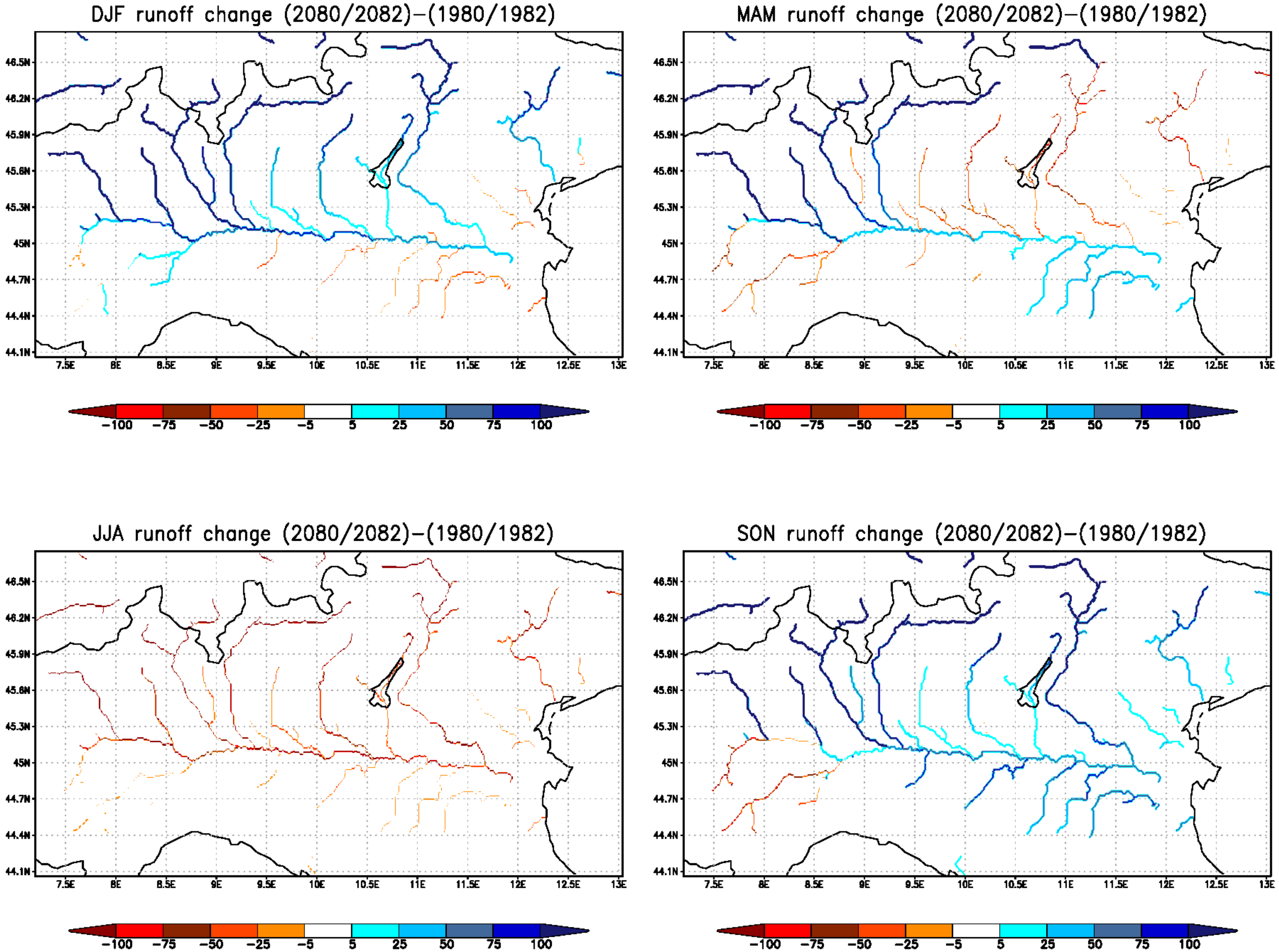
Courtesy of Martin Beniston

Average discharge by 2100 (mm, Rhone)

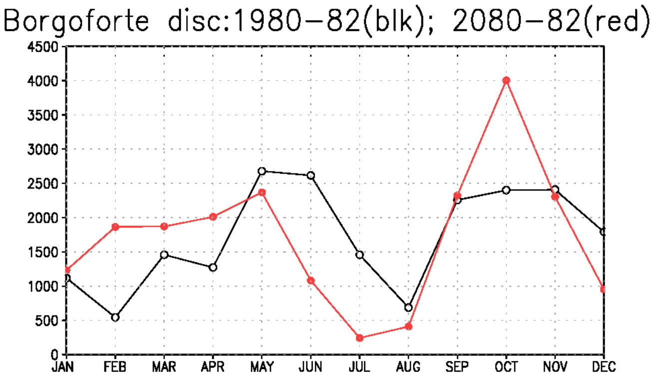
Beniston, 2004:
Climatic Change and Impacts,
Springer Publishers

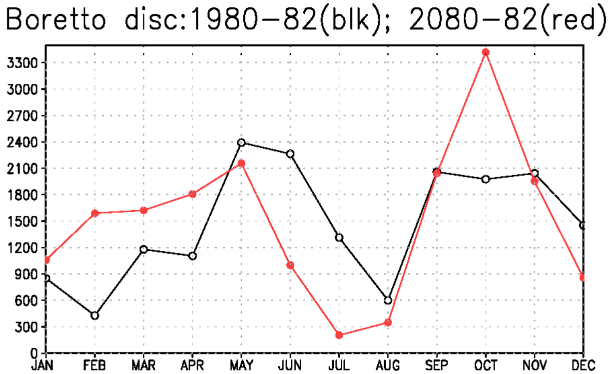


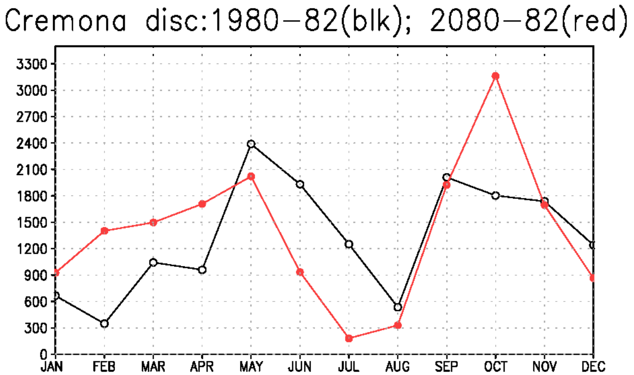
Average discharge change by 2100 (%, Po)

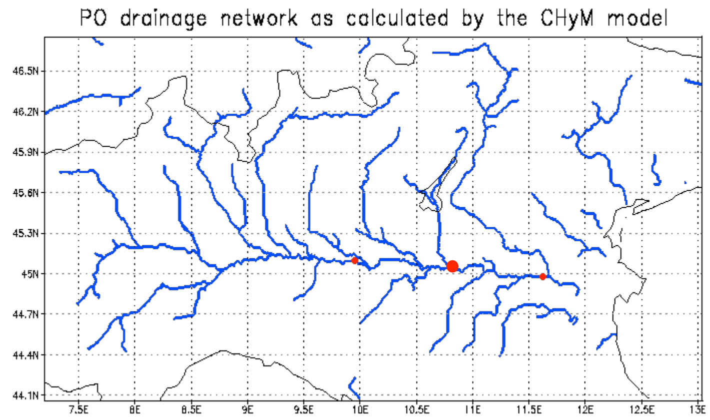


Coppola 2010,
personal comun.









- •Shift of the spring peak toward the early part of the season
- •Decrease of runoff during the summer months (Jul. and Aug.)
- •Increase of the autumn runoff

Coppola 2010, personal comun.

Case studies

Po river (Italy) (1 km resolution; 110945.0 km2 drained area)
5 years RegCM-ERA40 simulation 1995-2000
3 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

Niger - Volta river (West-Africa)(9.5 km; Niger 2494084 km2,
Volta 434235 km2 drained area)
120 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

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Nakdong 15848 km2, Kum 6769 km2 drained area)

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Yangtze 564594 km2)
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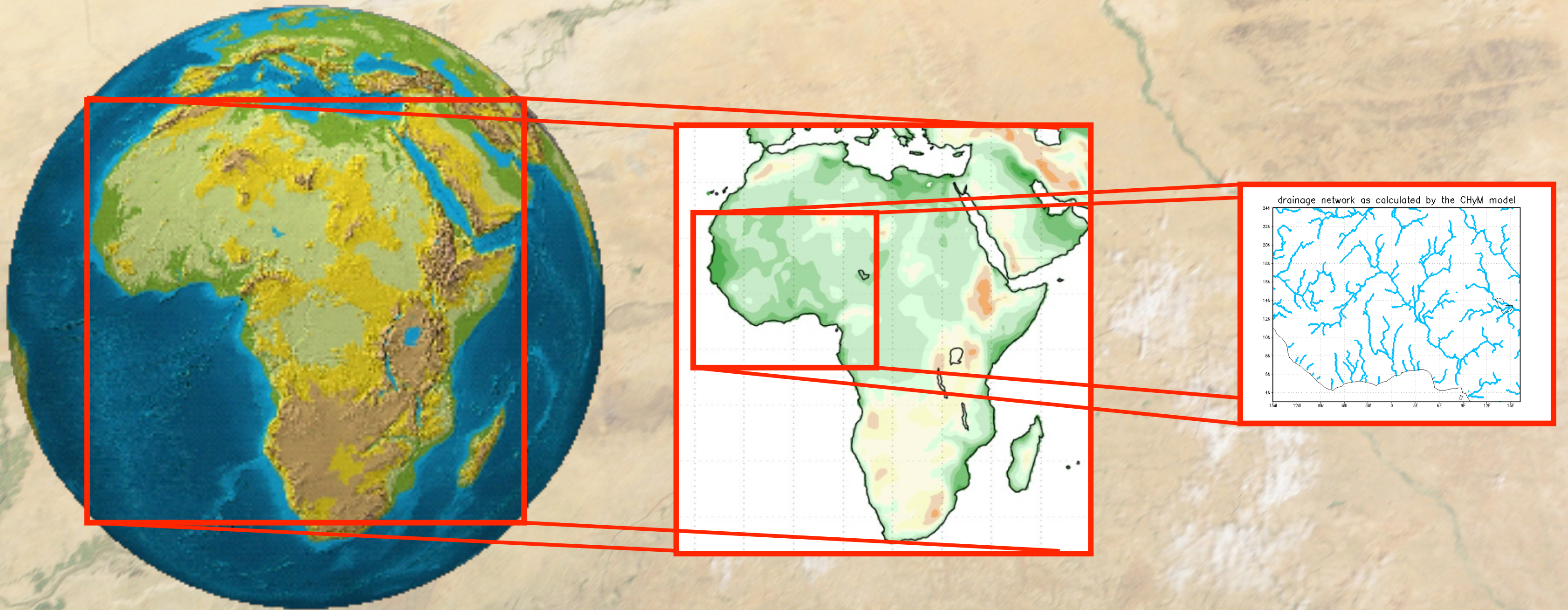
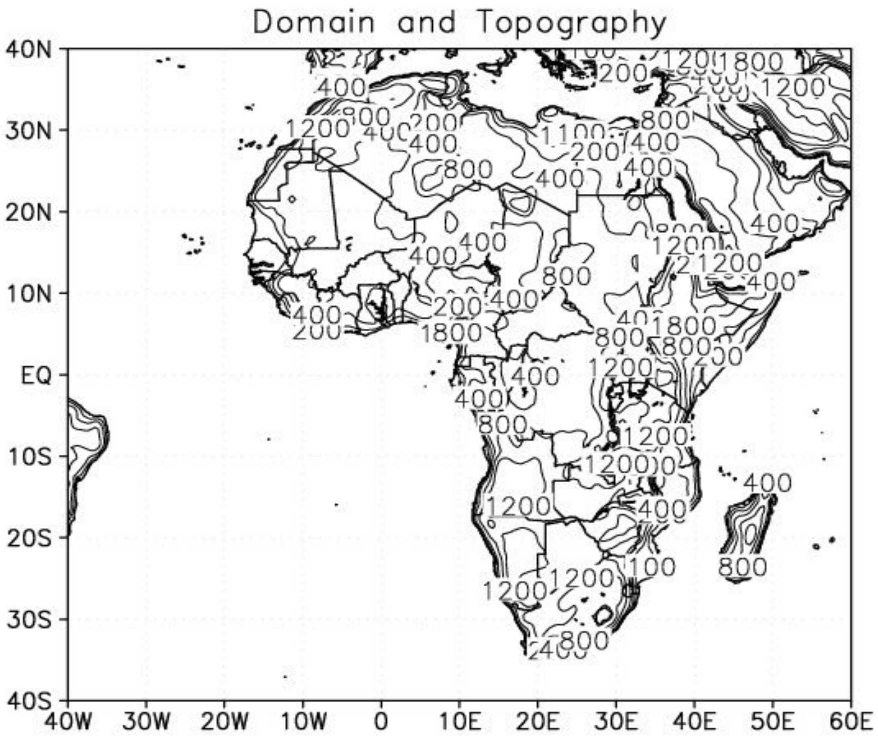

drainage network as calculated by the CHyM model

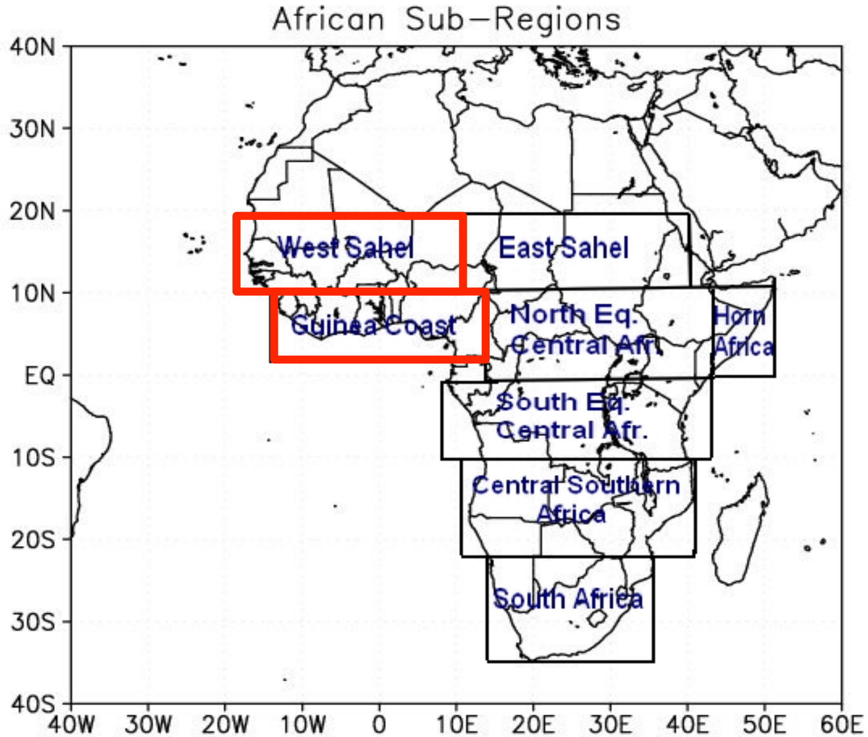
Regional Climate Simulations

2. > Validation of RegCM3 over Africa driven by ERA-Interim reanalysis

3. > Regional model simulations of projected climate change over Africa

❑ Domain, Topography, Subregions and Data

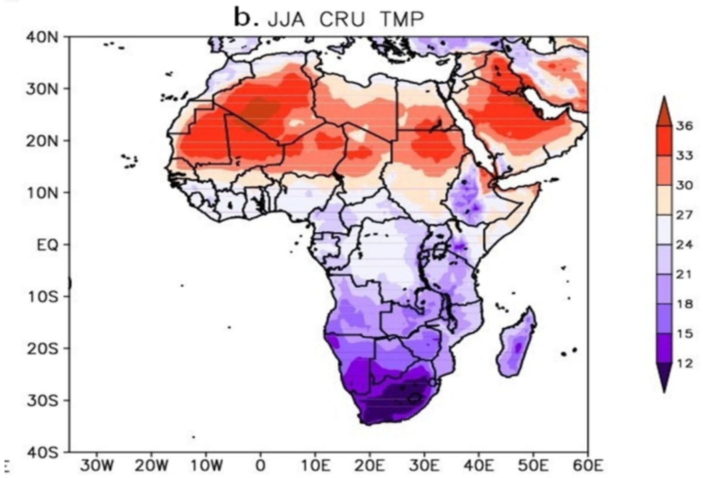




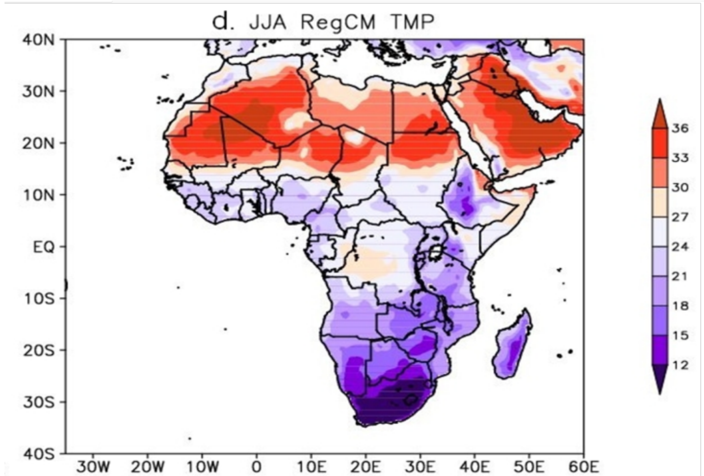
Data	RegCM3	ERAIM	GPCP	CRU	FEWS
Period	1989-2005	1989-2005	1989-2005	1989-2002	2001-2005

❑ Temperature Climatology

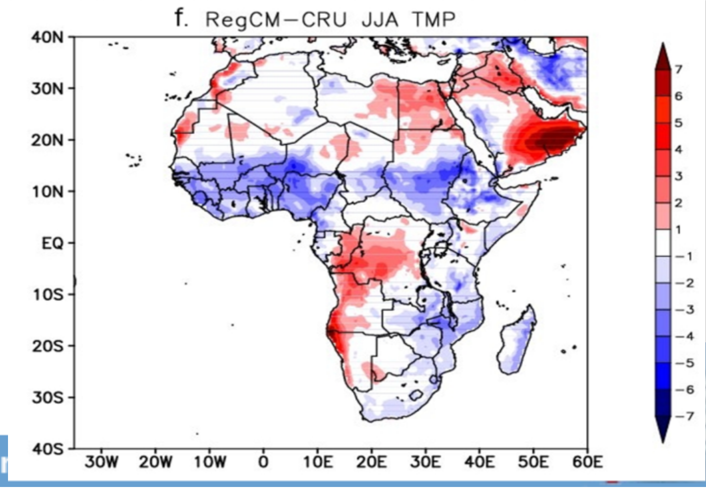
❖ CRU



❖ RegCM3

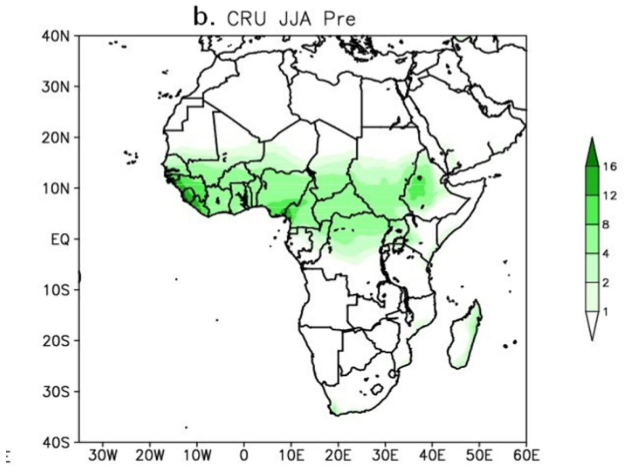


❖ RegCM3-CRU

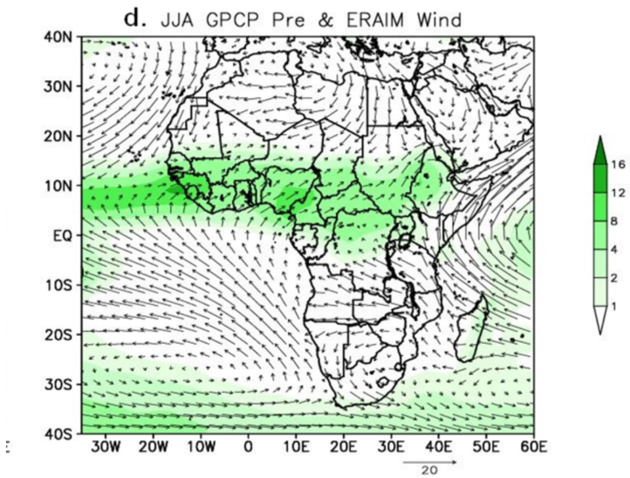


❑ Precipitation Climatology

❖ CRU

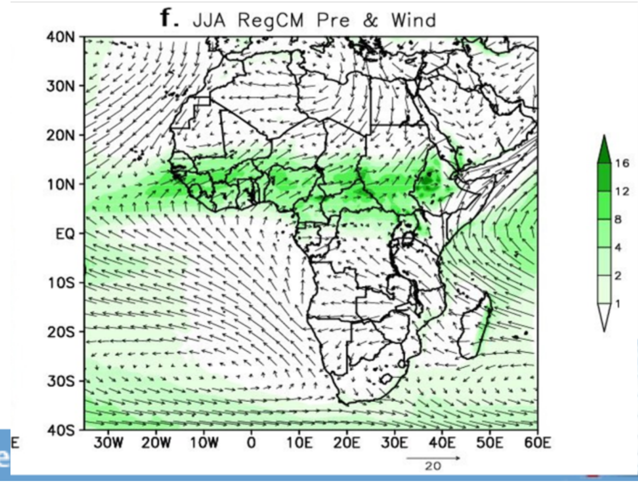


❖GPCP



✓ Discrepancies between Observed Climatologies: Maxima over Ethiopia Highlands in CRU not found in GPCP

❖ RegCM3



✓Additional Peaks over Complex Terrains not found in Observation

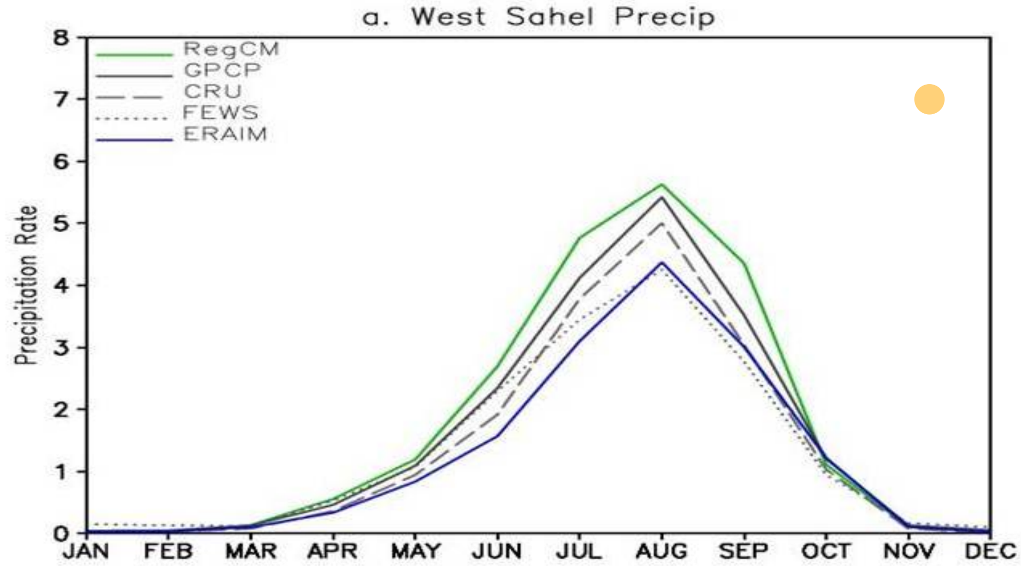
❑ Mean Annual Cycle over Homogeneous Climate Subregions

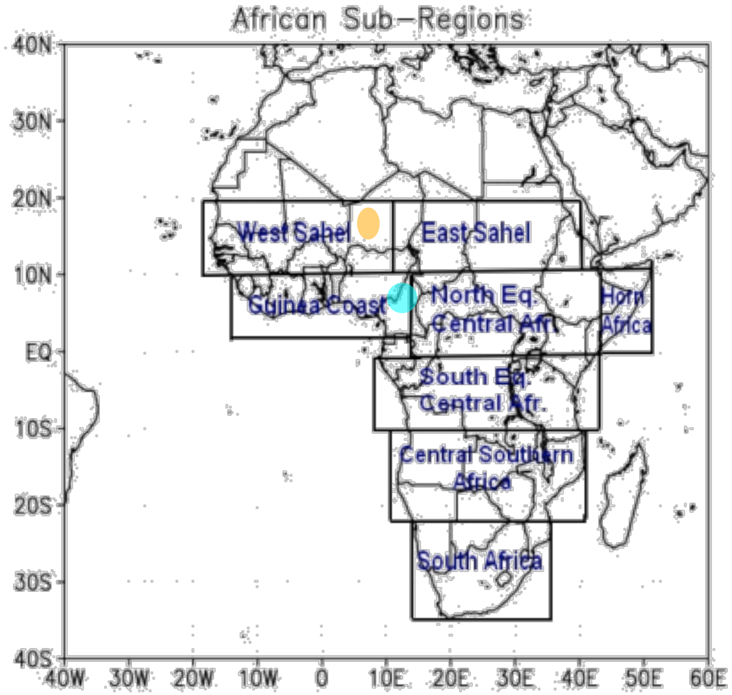
❖ Semi-Arid Subregions:

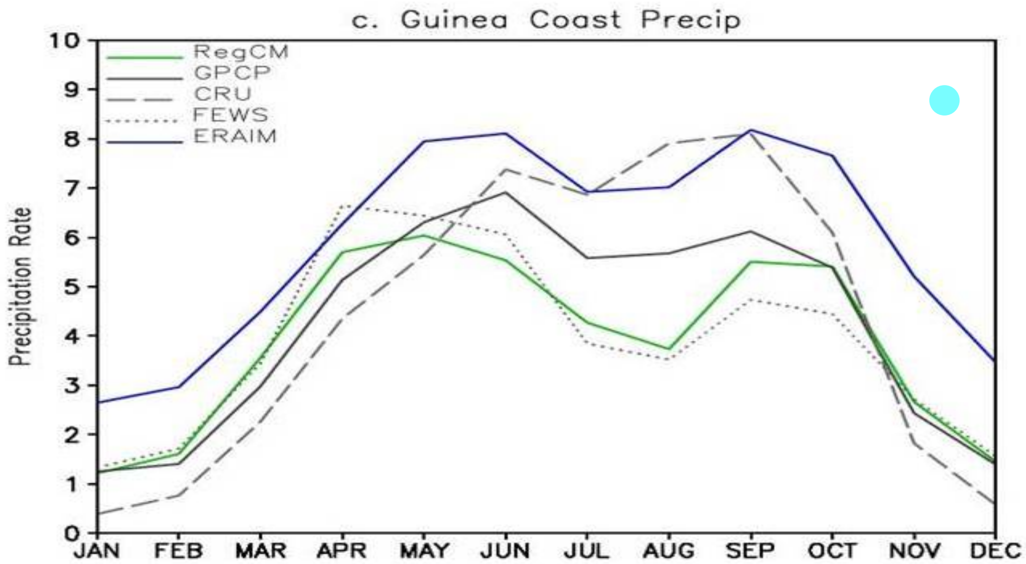
✓ West Sahel: JAS

❖ Equatorial Subregions:

✓ Guinea Coast: MJJ and ASO







Regional Climate Simulations

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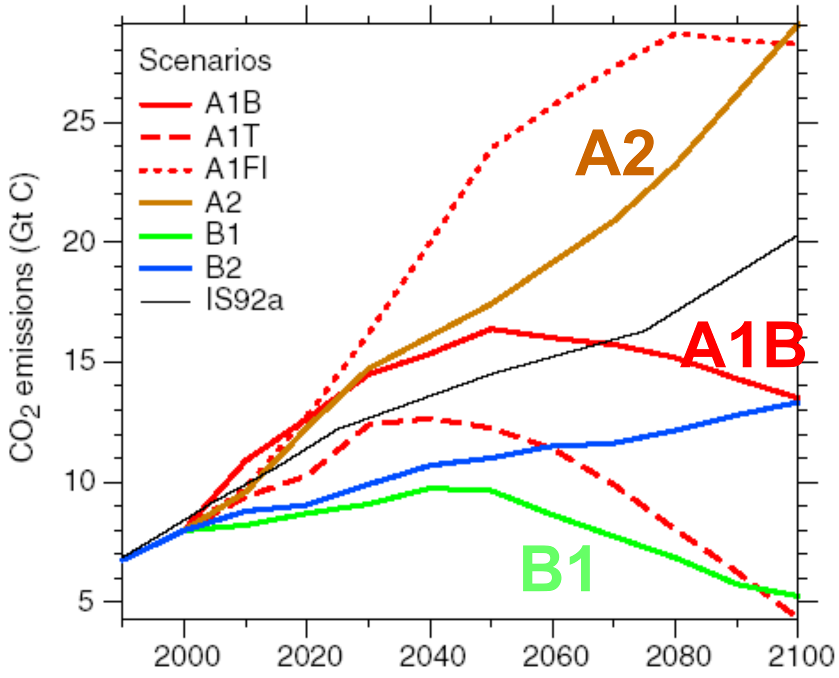
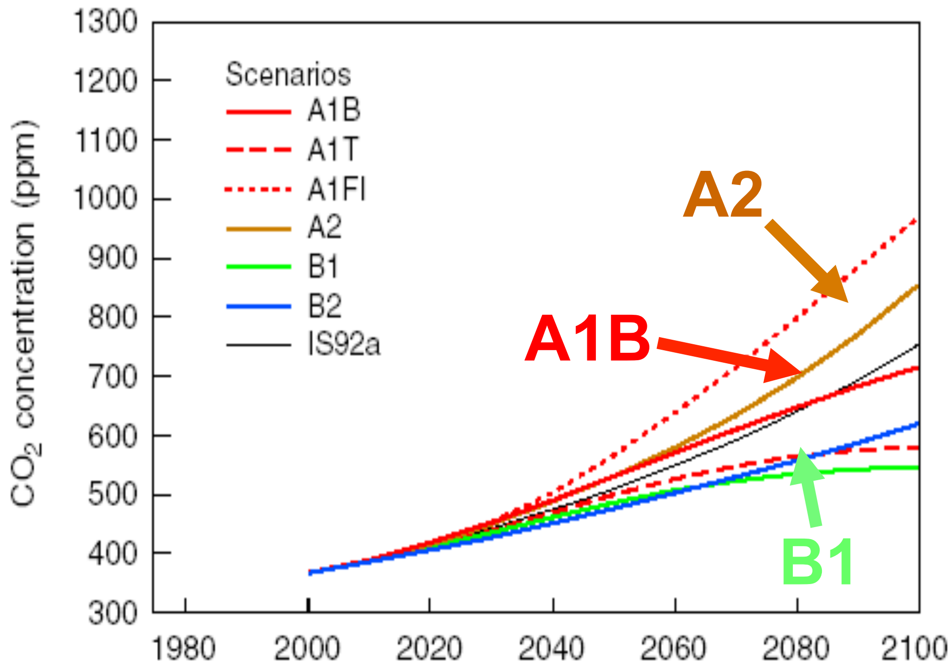
❑ **Future Scenarios of Concentrations and Emissions of Greenhouse Gases**

CO_2 Emissions



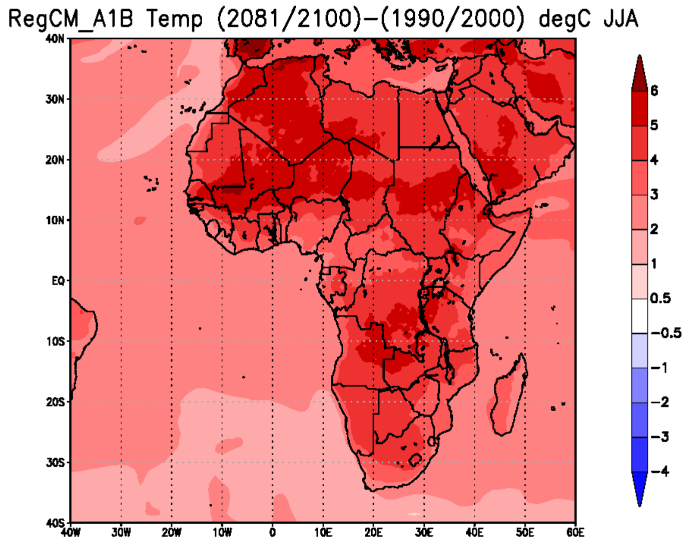
CO_2 Concentrations

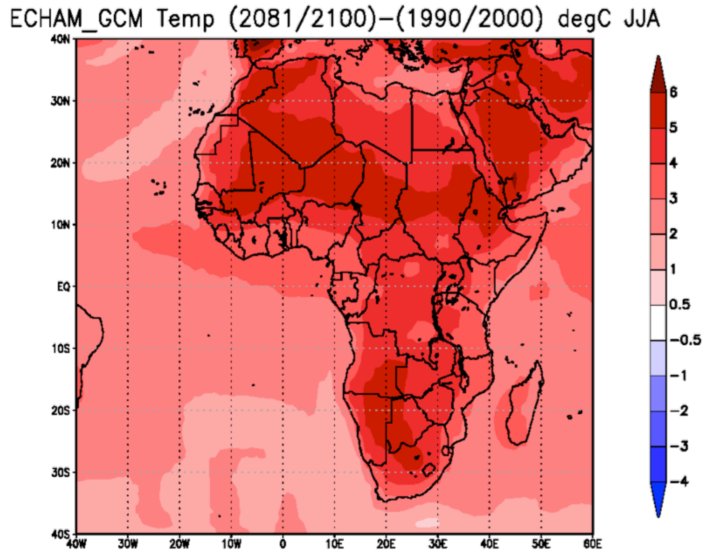


❑ Temperature Change

RegCM3 ECHAM5

JJA

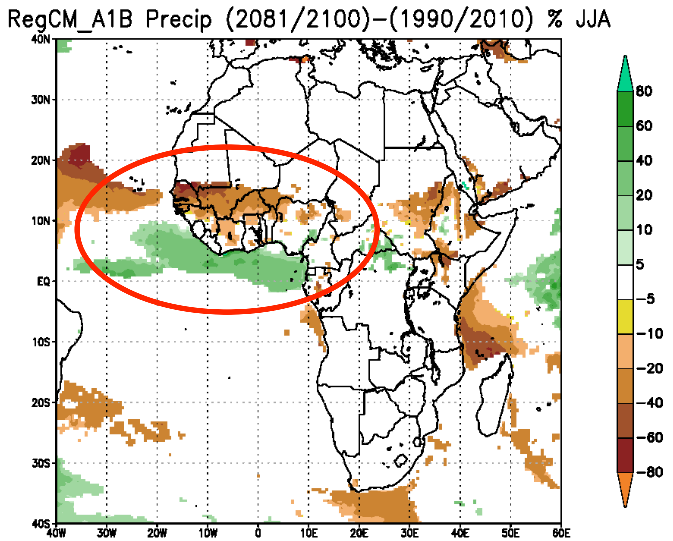


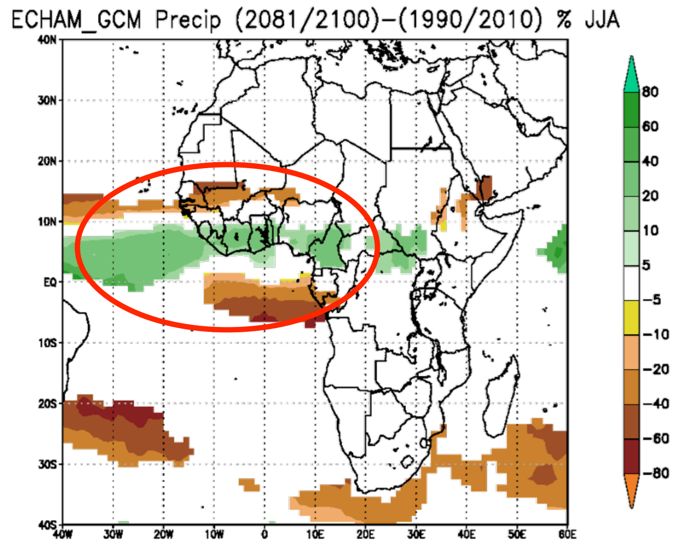


❑ Precipitation Change

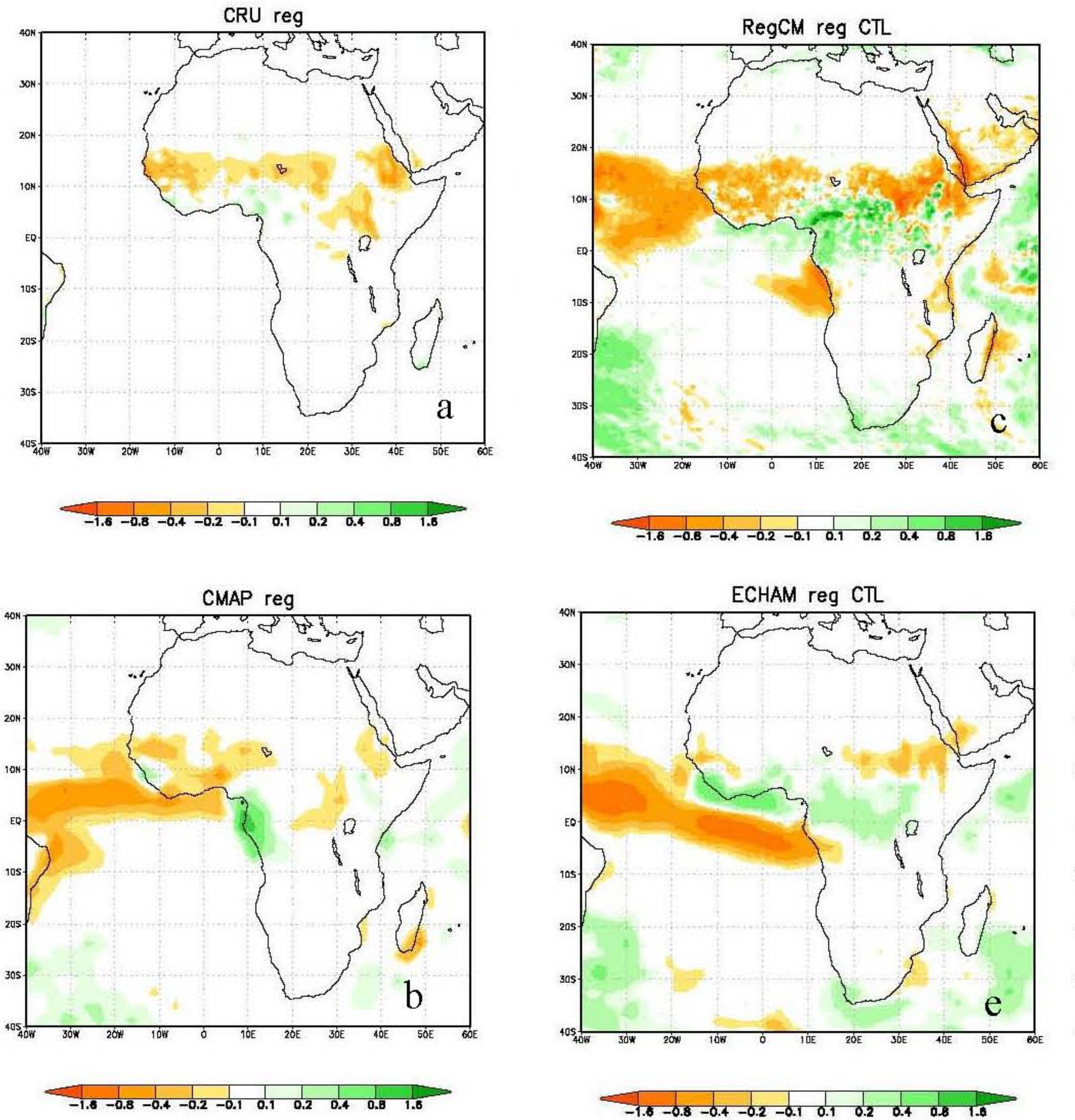
RegCM3 | ECHAM5

JJA





❑ Precipitation Regressions into ENSO3.4 SST anomaly i



Difference in regional climate response to local forcing

We want to assess the precipitation variability in western Africa connected to SST forcing compared to the effects of soil moisture feedback.
Statistical approach by Notaro et al.2008

$$\lambda = \frac{\mathrm{cov}(s(t-\tau), a(t))}{\mathrm{cov}(s(t-\tau), s(t))}$$

λ is the instantaneous feedback of a variable ***s*** on a variable *a* at time ***t***,
where

- ***s*** is a slow varying variable (Soil Moisture or SST)
- ***a*** is a fast varying atmospheric variable (Precipitation)

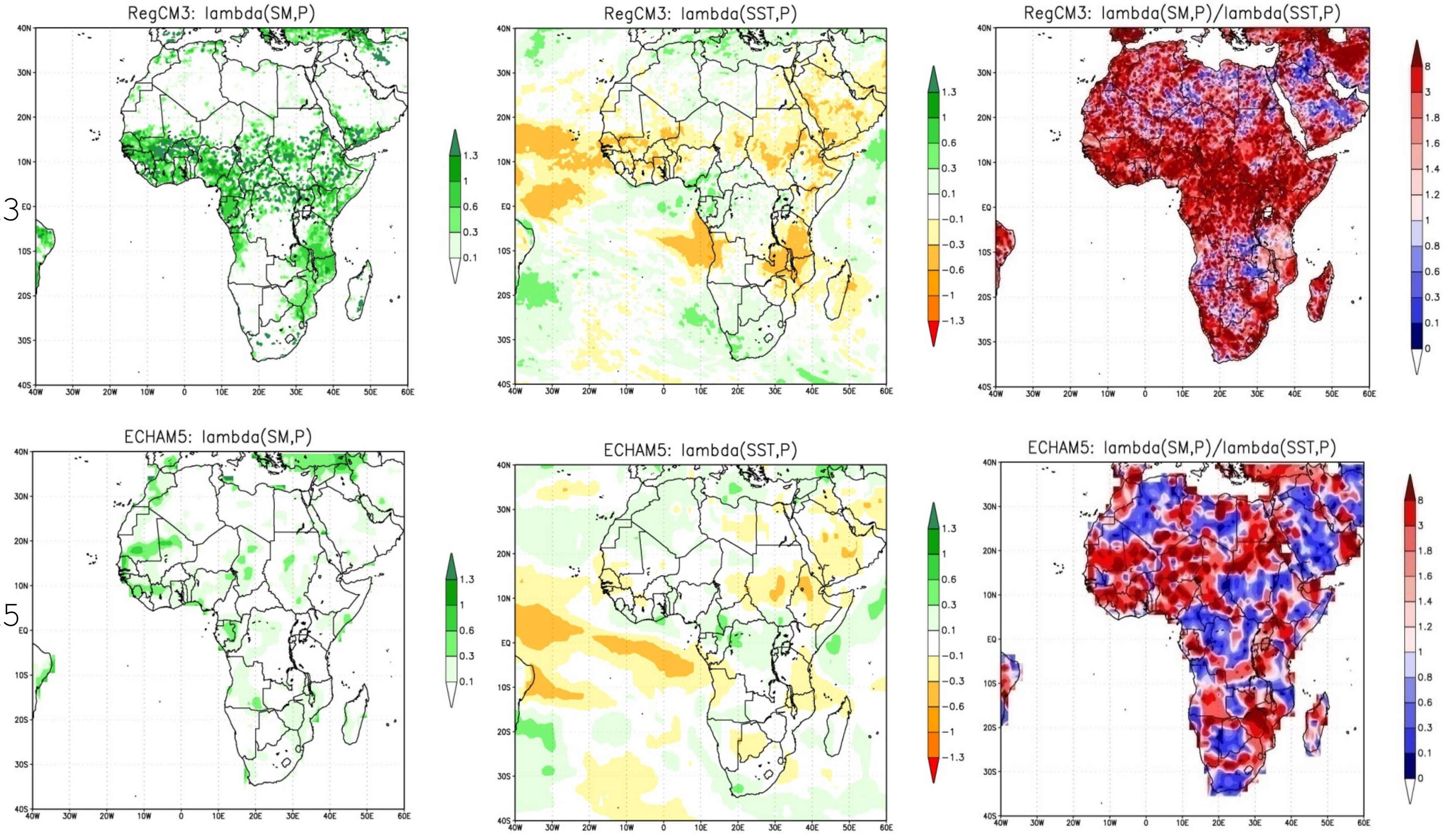
λ represents the fraction of precipitation change attributed to variations in mothly Soil Moisture or SST

❑ Feedback parameter λ

λ(SM,P) λ(SST,P) λ(SM,P)/λ(SST,P)

RegCM3

ECHAM5



4. Hydrological Simulations

1 > Experiment Design

2 > Calibration Runs

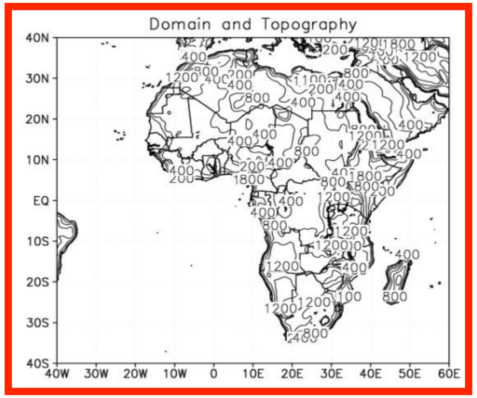
3 > Transient Scenario Simulations

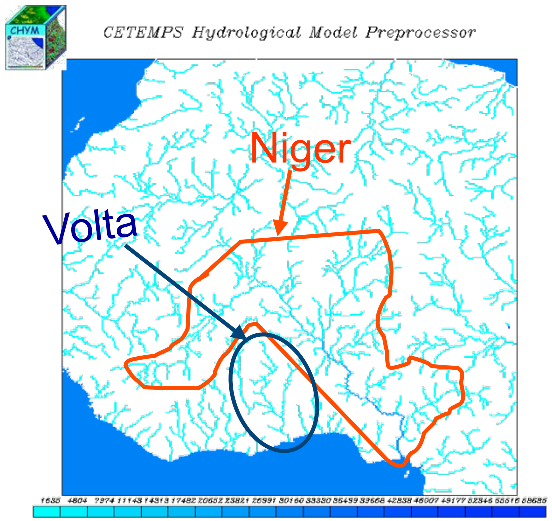
Experiment Description

Regional Climate Model (RegCM3) simulations

►*Control simulation using ERA-Interim as boundary conditions (1990-2007) [Sylla et al. 2009]*

►*Scenario simulations using ECHAM5-GCM A1B (1980-2100) [Mariotti et al. 2010, submitted]*





Cetemps Hydrological Model **CHyM** [*Coppola et al. 2007*] has been coupled with RegCM3

► *hydrological model calibration run - regional model perfect boudary simulation output as input (1990-2005)*

► *Transient hydrological scenario simulations - regional climate model output from the A1B transiet simulation as input (1980-2100)*

4.Hydrological Simulations

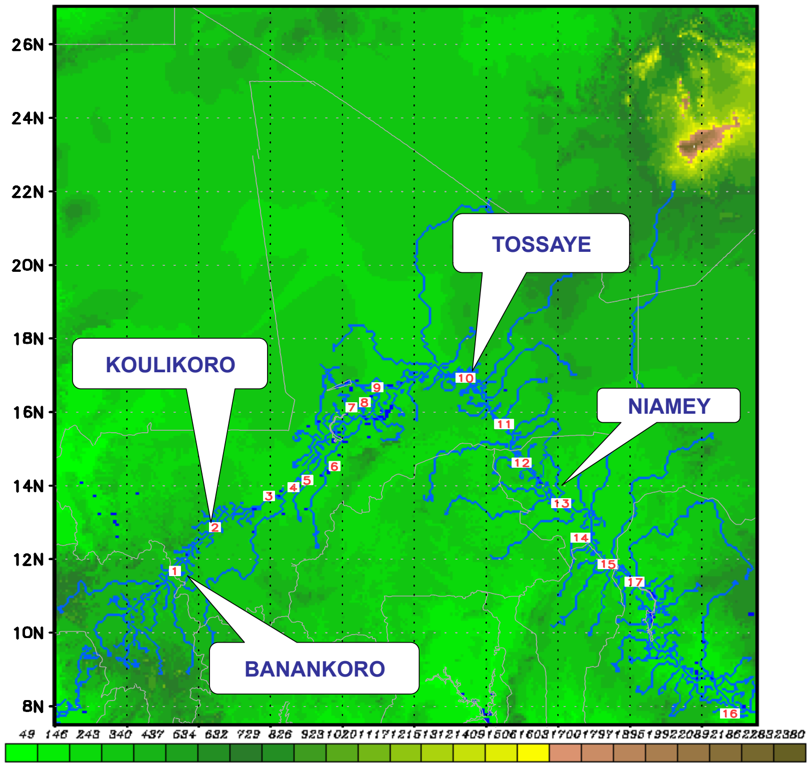
1 > Experiment Design

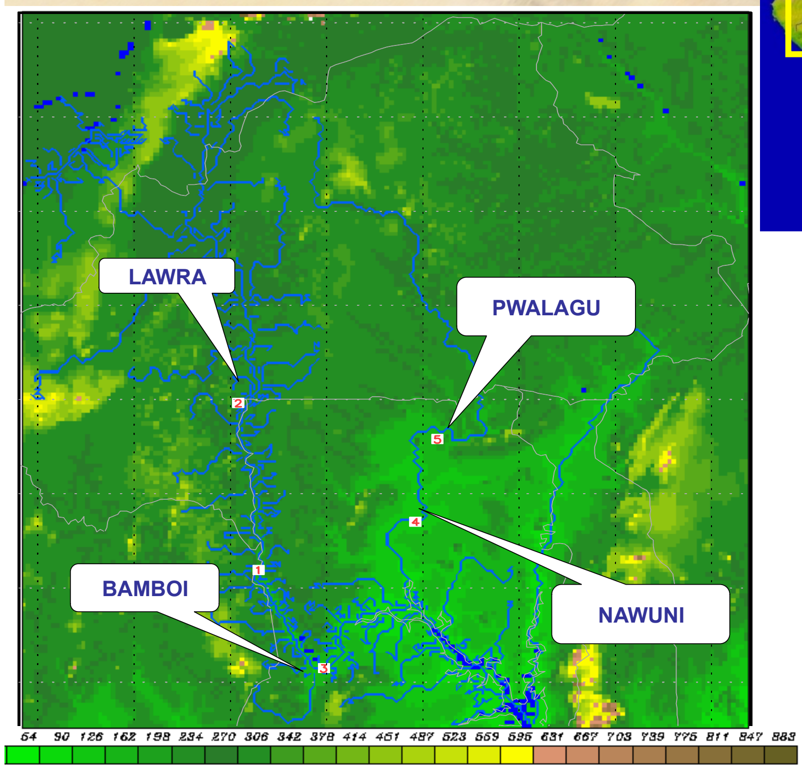
2 > Calibration Runs

3 > Transient Scenario Simulations

Niger River

Volta River





Niger:

•Length 4180 km , it s the third-longest river in Africa, after the Nile and the Congo/Zaire Rivers, and the longest and largest river in West Africa.

•The catchment area covers 7.5% of the continent and spread over 10 countries.

•The water is partially regulated through dams mainly used for hydropower and for irrigation.

Volta:

•Length 1600 km

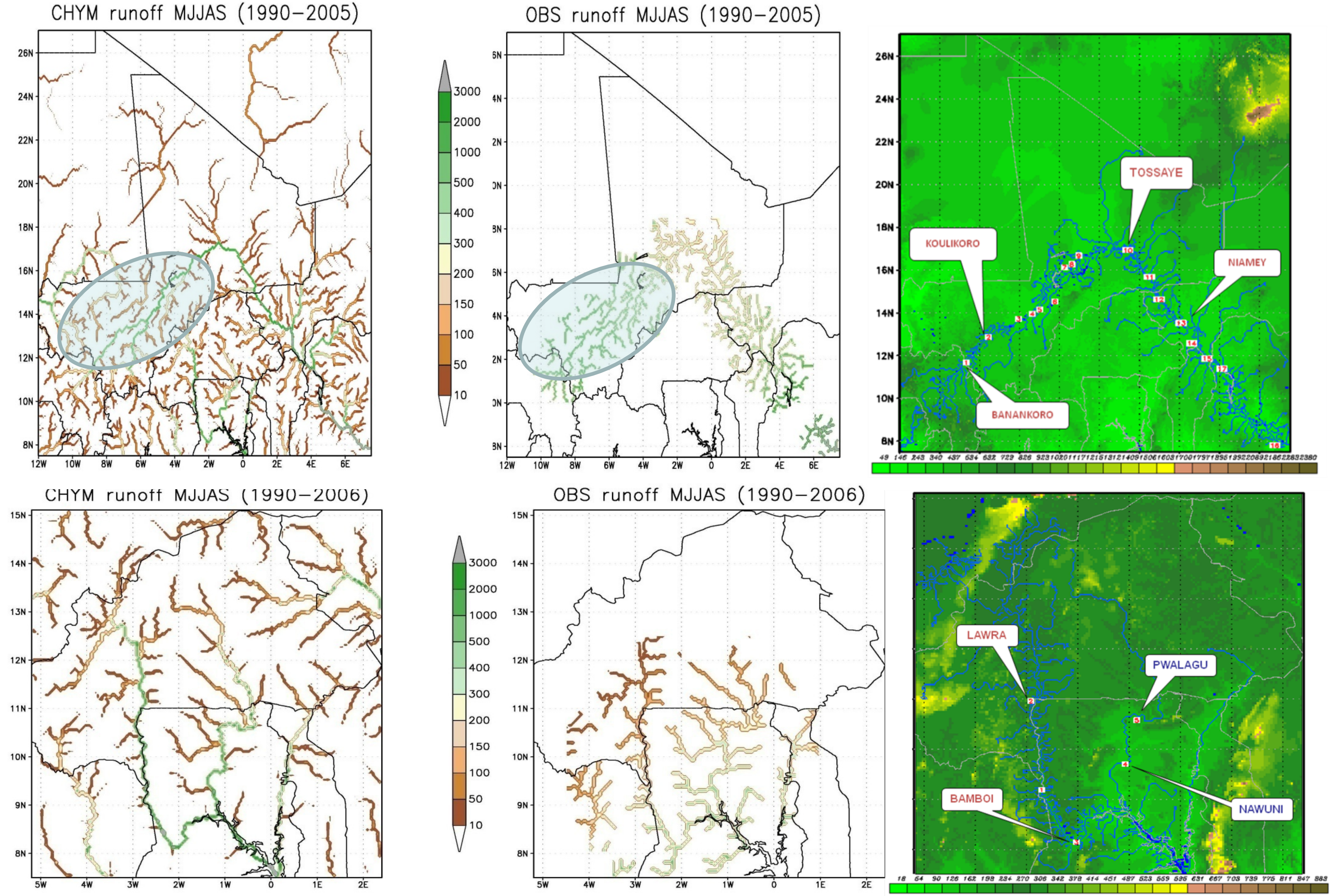
•The catchment area stretches over approximately 400 000 km^2, making it the ninth most important river basin in Sub-Saharan Africa.

•Situated in a very arid region, this is one of the poorest regions of the world.

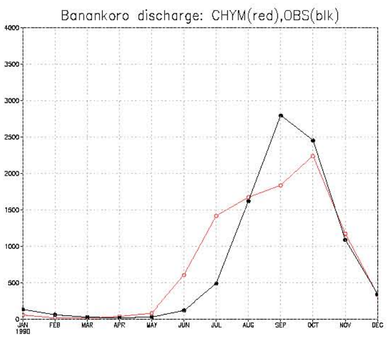
•There is extensive use of the water resources for electricity generation and irrigation.

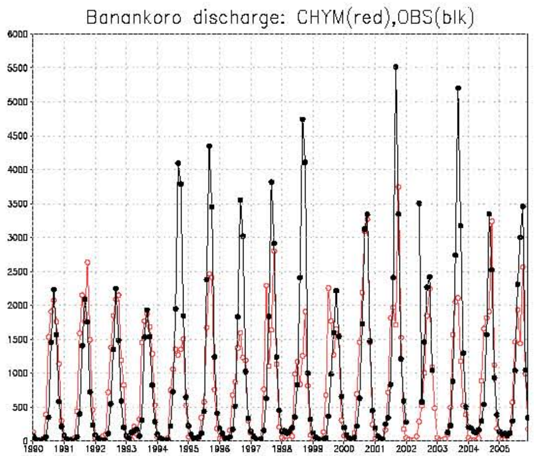
•The Akosombo dam in Ghana generates 80% of the power produced in the country.

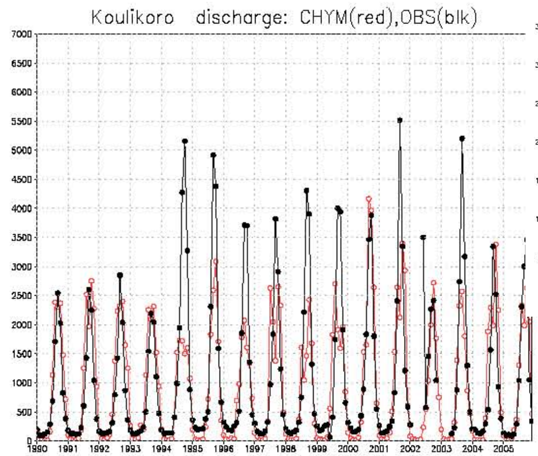
Seasonal Runoff for MJJAS

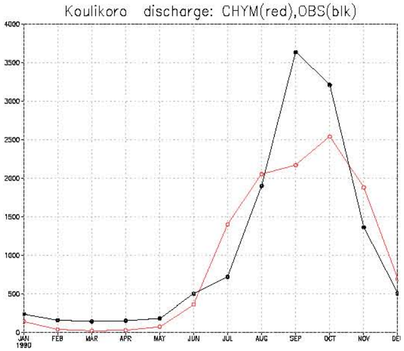


Niger Monthly Discharge (1990-2005)



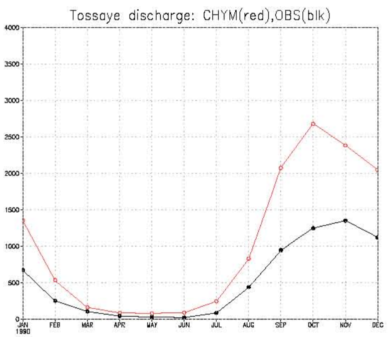


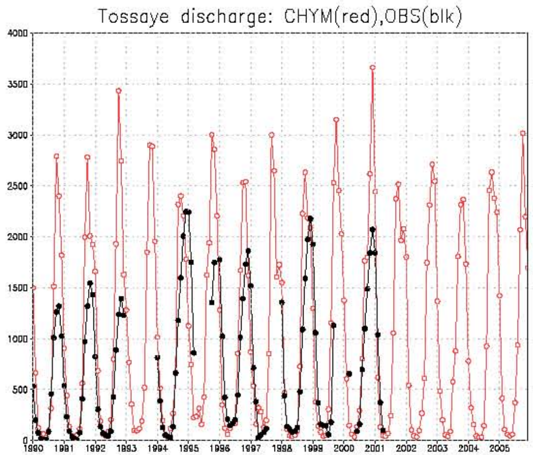


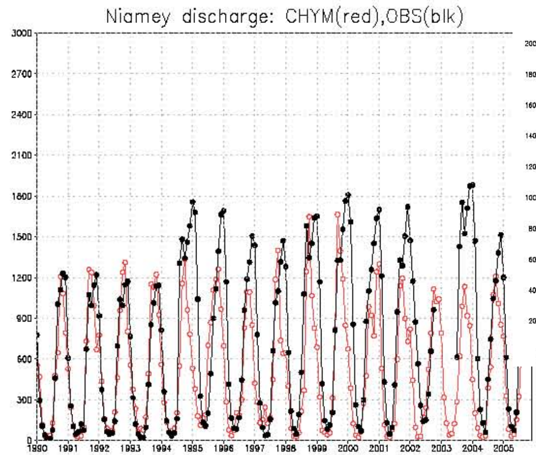


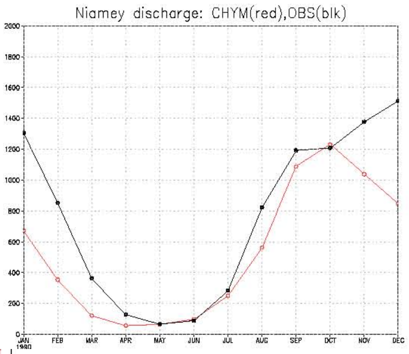
(a)

(b)



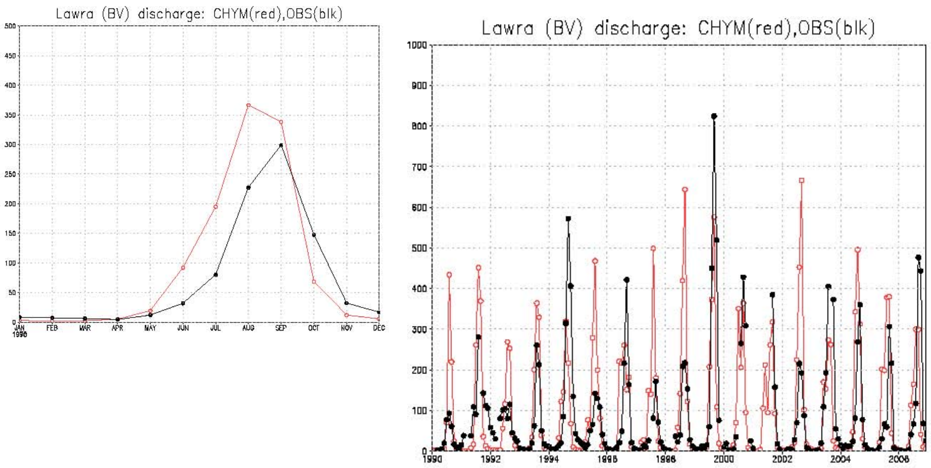




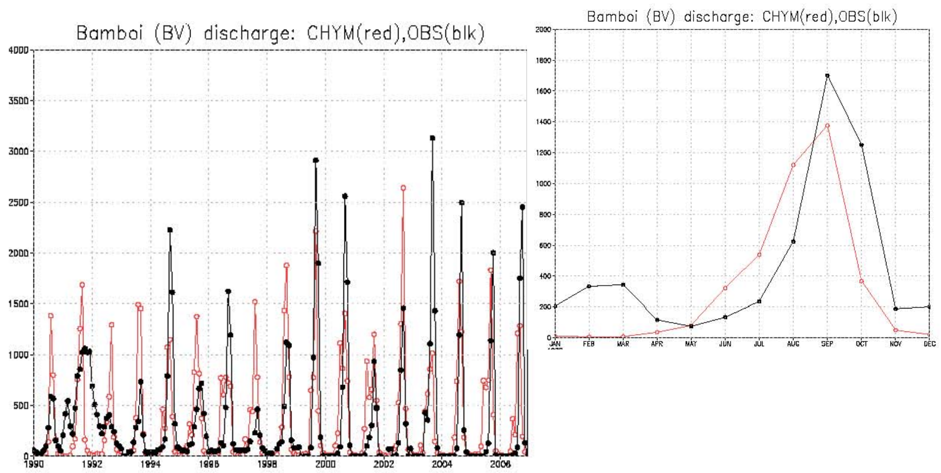


NIGER monthly	Banankoro	Koulikoro	Tossaye	Niamey
CHyM-Obs Bias (m^3/s)	42.24	-103.42	506.81	-234.60
CHyM-Obs Bias (%)	5.84	-9.46	95.95	-30.20
Correlation Coeff.	0.78	0.76	0.95	0.77
RMSE (m^3/s)	35.88	59.47	19.82	30.33

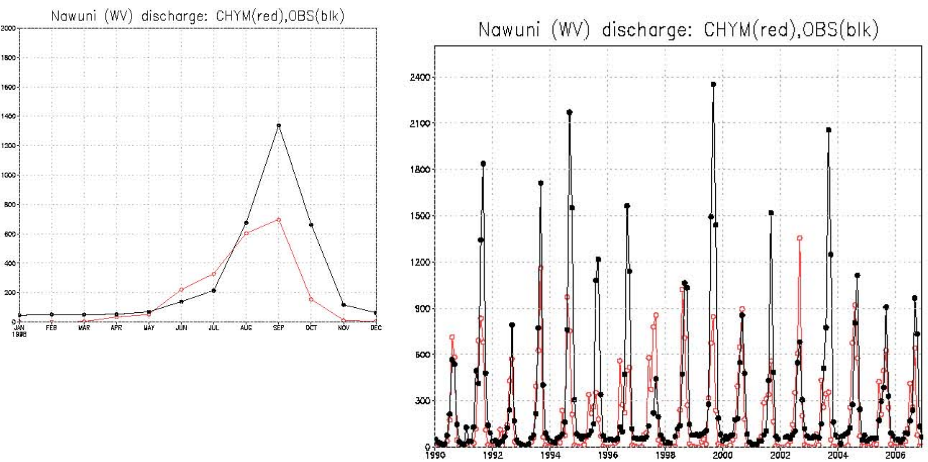
Volta Monthly Discharge (1990-2005)

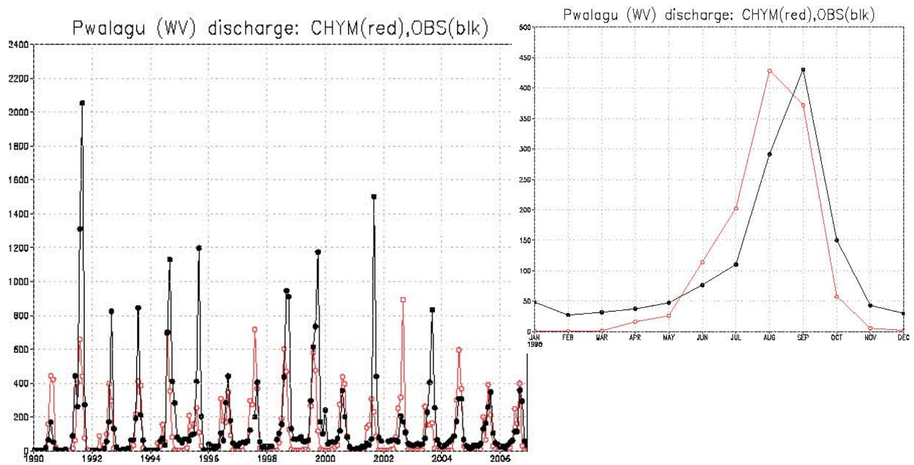


(a)



(b)





Volta monthly	Lawra	Bamboi	Nawuni	Pwalagu
CHyM-Obs Bias (m^3/s)	30.44	-11.49	-82.60	2.8
CHyM-Obs Bias (%)	47.64	-3.17	-31.39	3.07
Correlation Coeff.	0.62	0.63	0.66	0.56
RMSE (m^3/s)	8.14	28.03	23.24	8.37

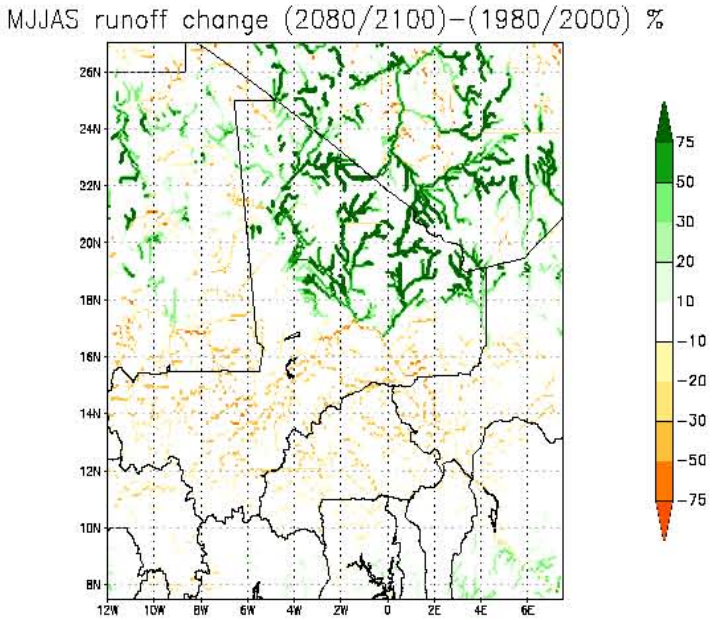
Hydrological Simulations

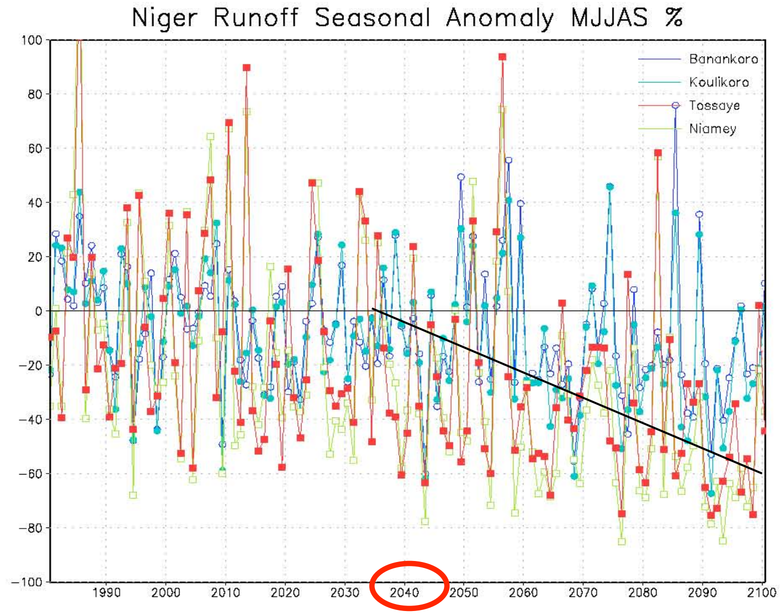
1 > Experiment Design

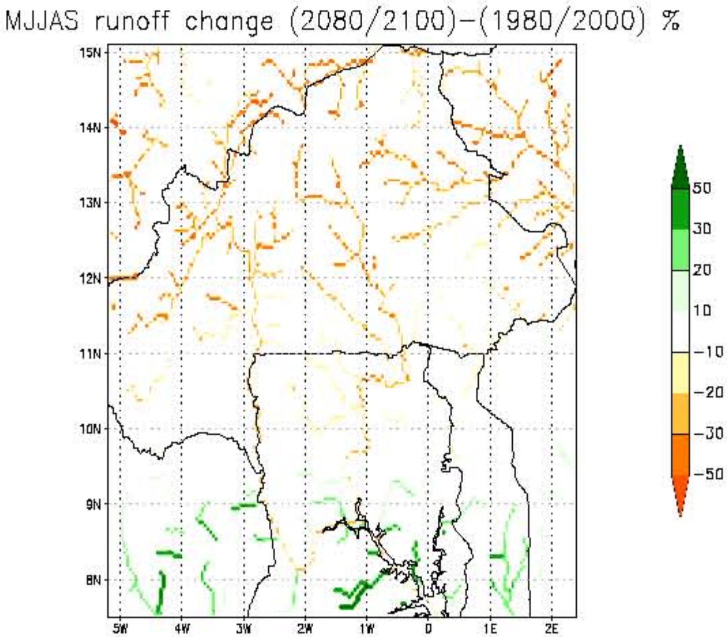
2 > Calibration Runs

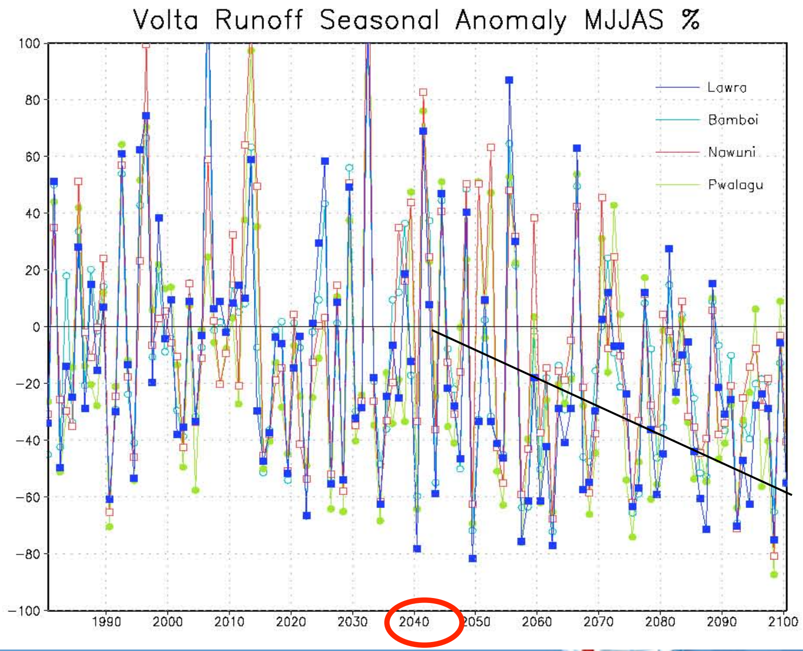
3 > Transient Scenario Simulations

Runoff Seasonal Change



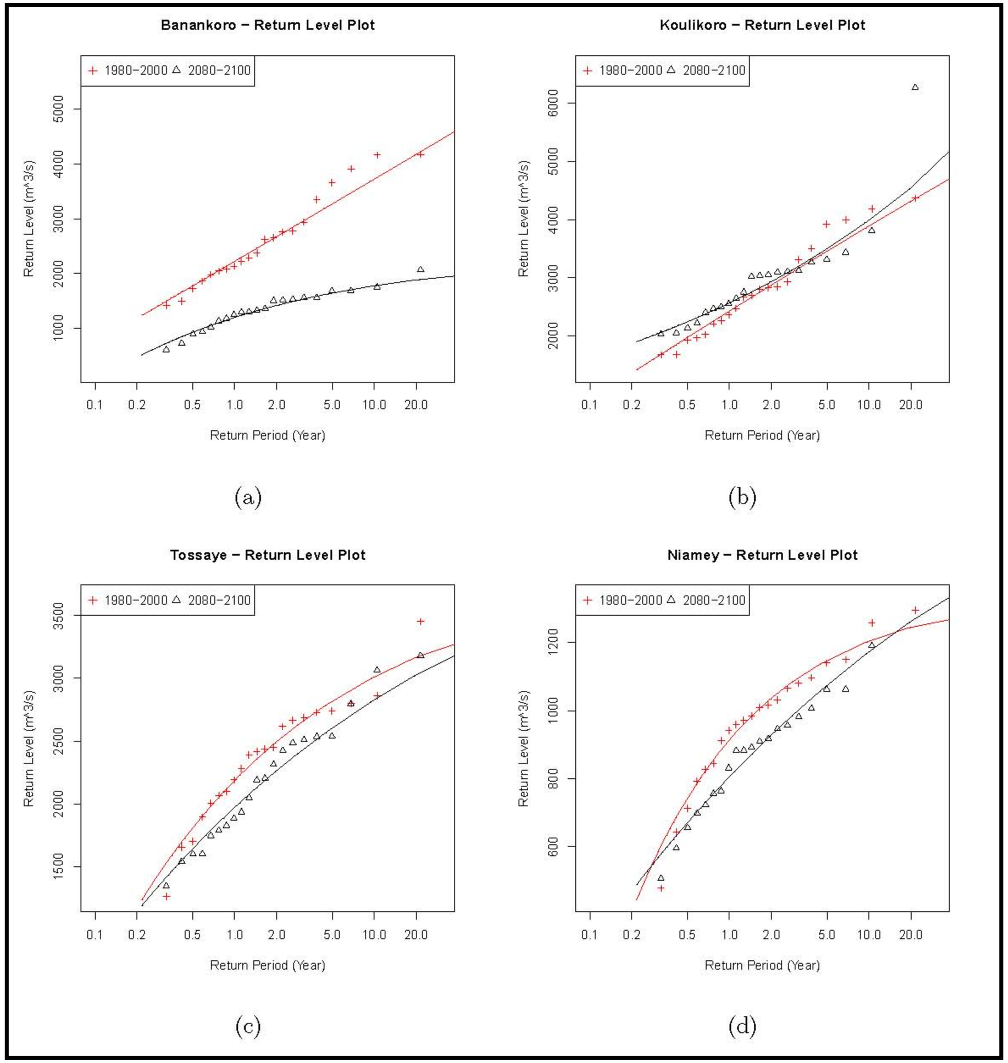




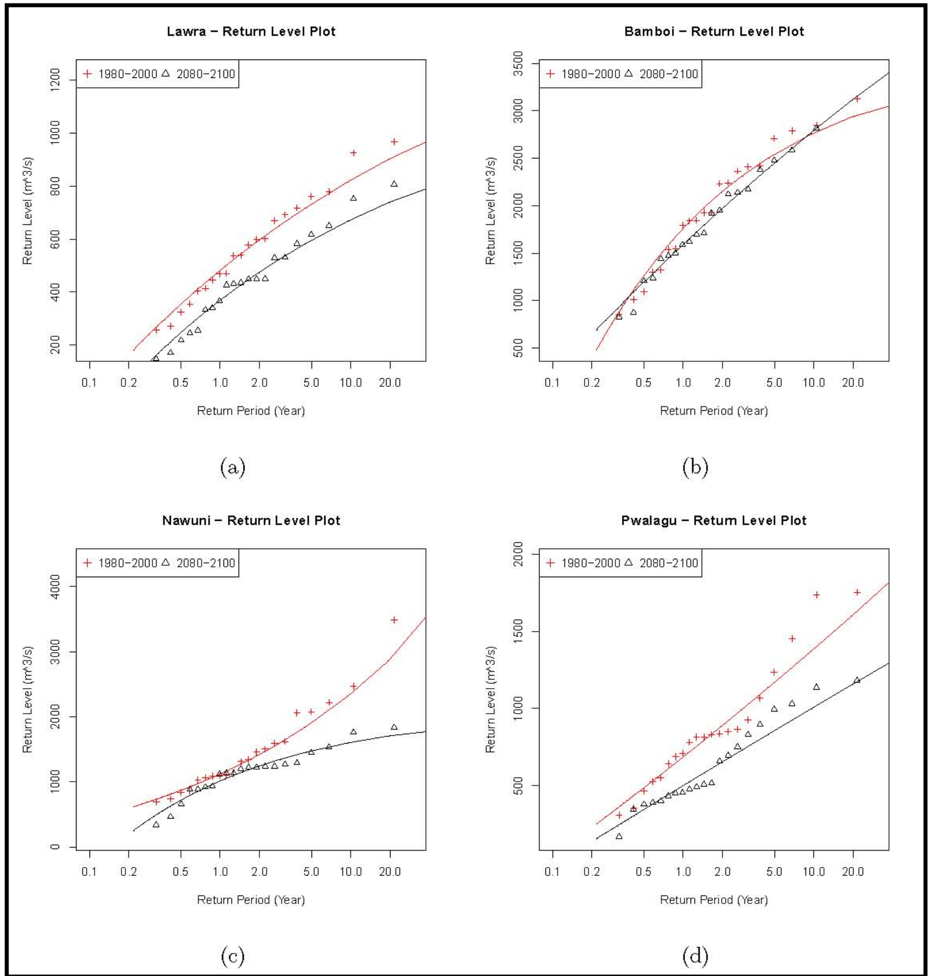


Generalized Extreme Value (GEV)

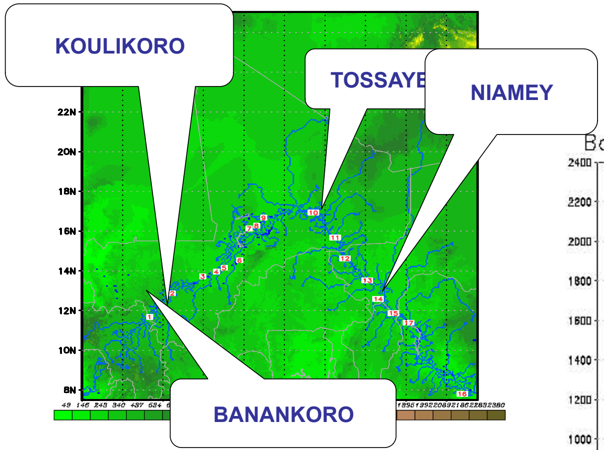
Niger

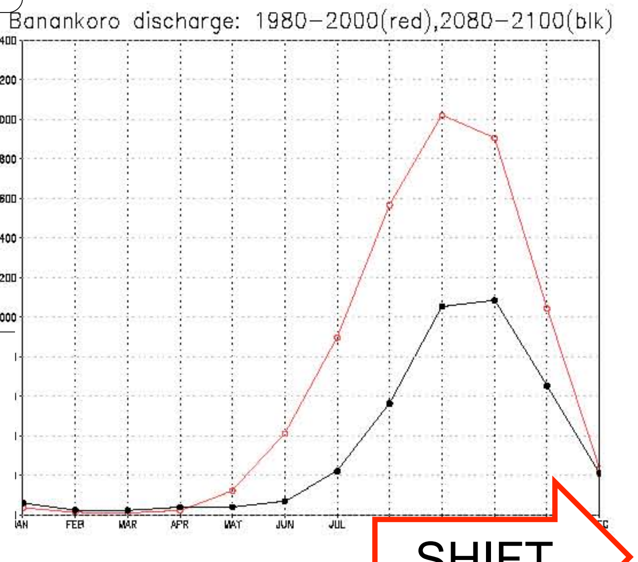


Volta

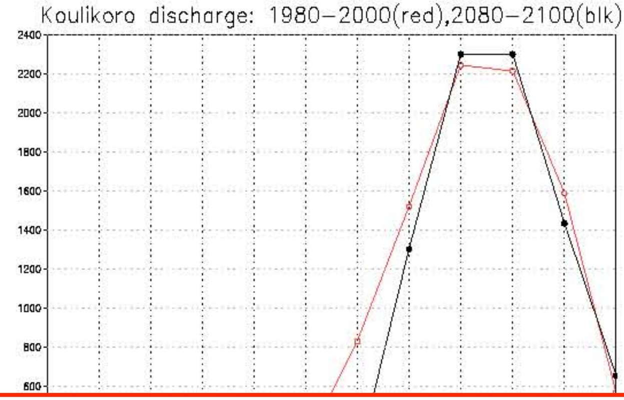


Niger – Mean Annual Cycle





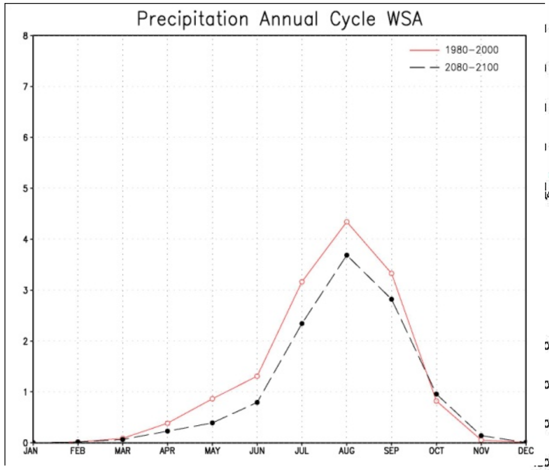
(a)

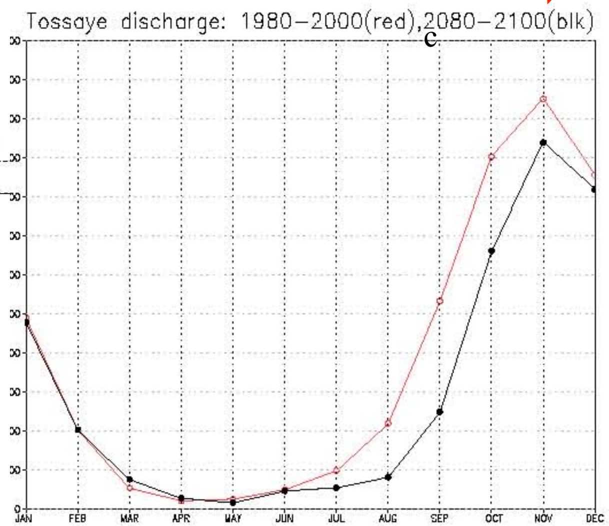


SHIFT

a

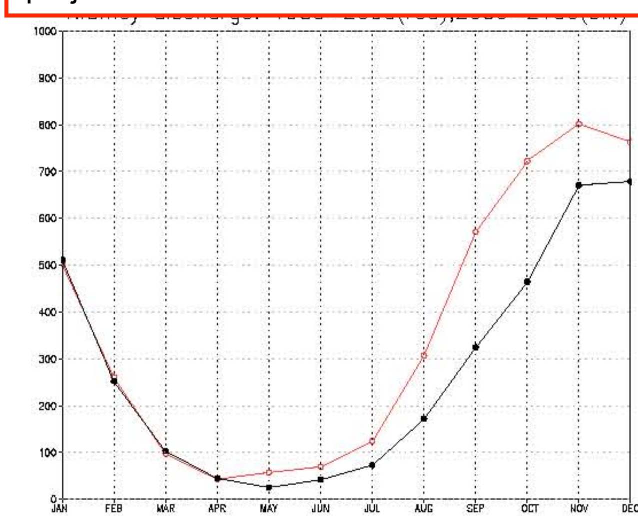
Biasutti and Sobel [2010-GRL] The shift of the discharge is probably due to the shift of the monsoon seasonal cycle in response to increasing greenhouses gases. In particular, the rainy season of the semi-arid African Sahel is projected to start later and become shorter.



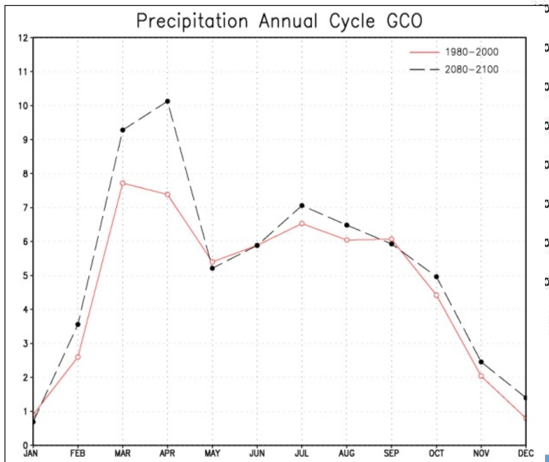


c

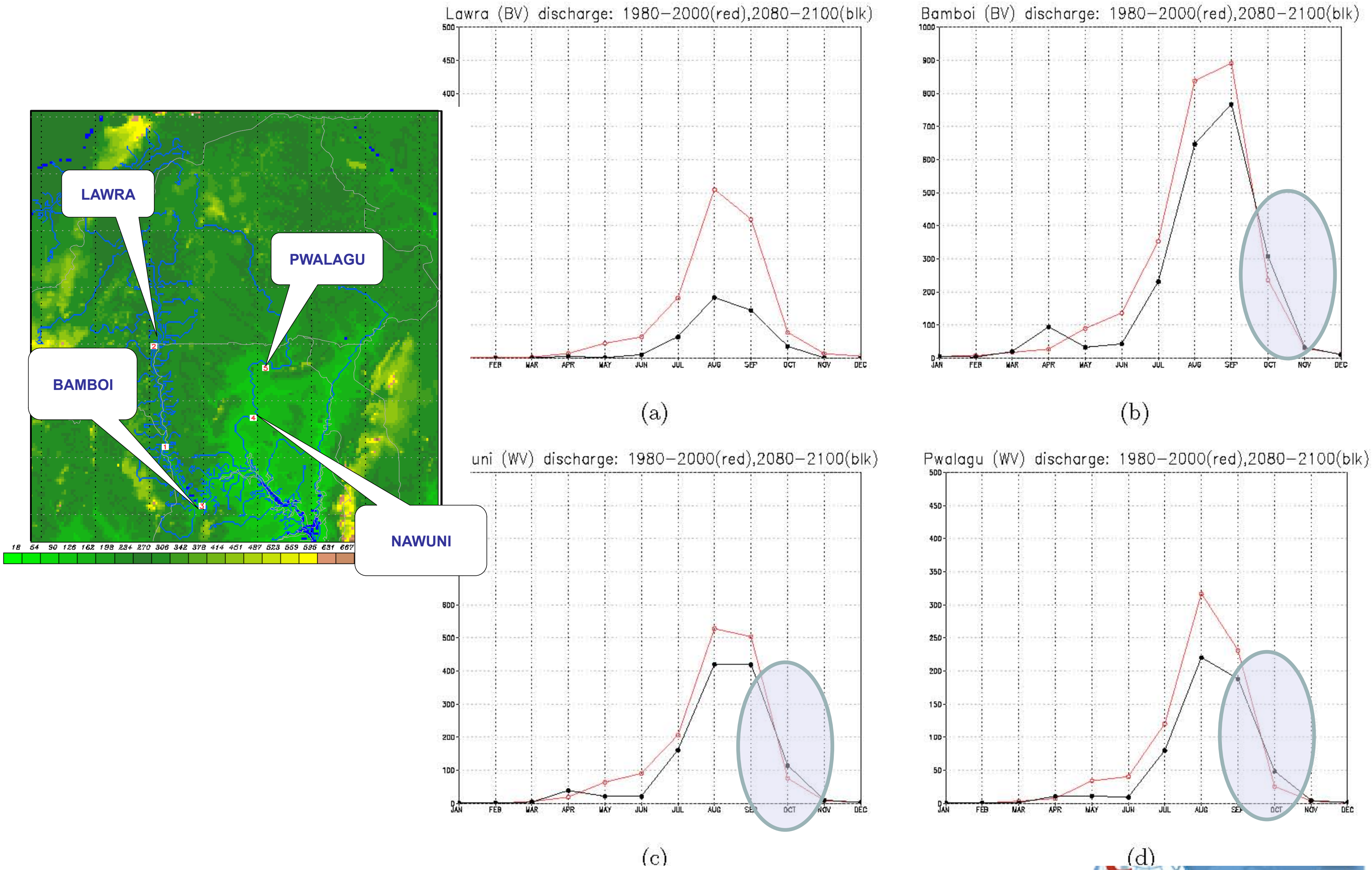
(c)



(d)



Volta – Mean Annual Cycle



Case studies

Po river (Italy) (1 km resolution; 110945.0 km2 drained area)
5 years RegCM-ERA40 simulation 1995-2000
3 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

Niger - Volta river (West-Africa)(9.5 km; Niger 2494084 km2,
Volta 434235 km2 drained area)
120 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

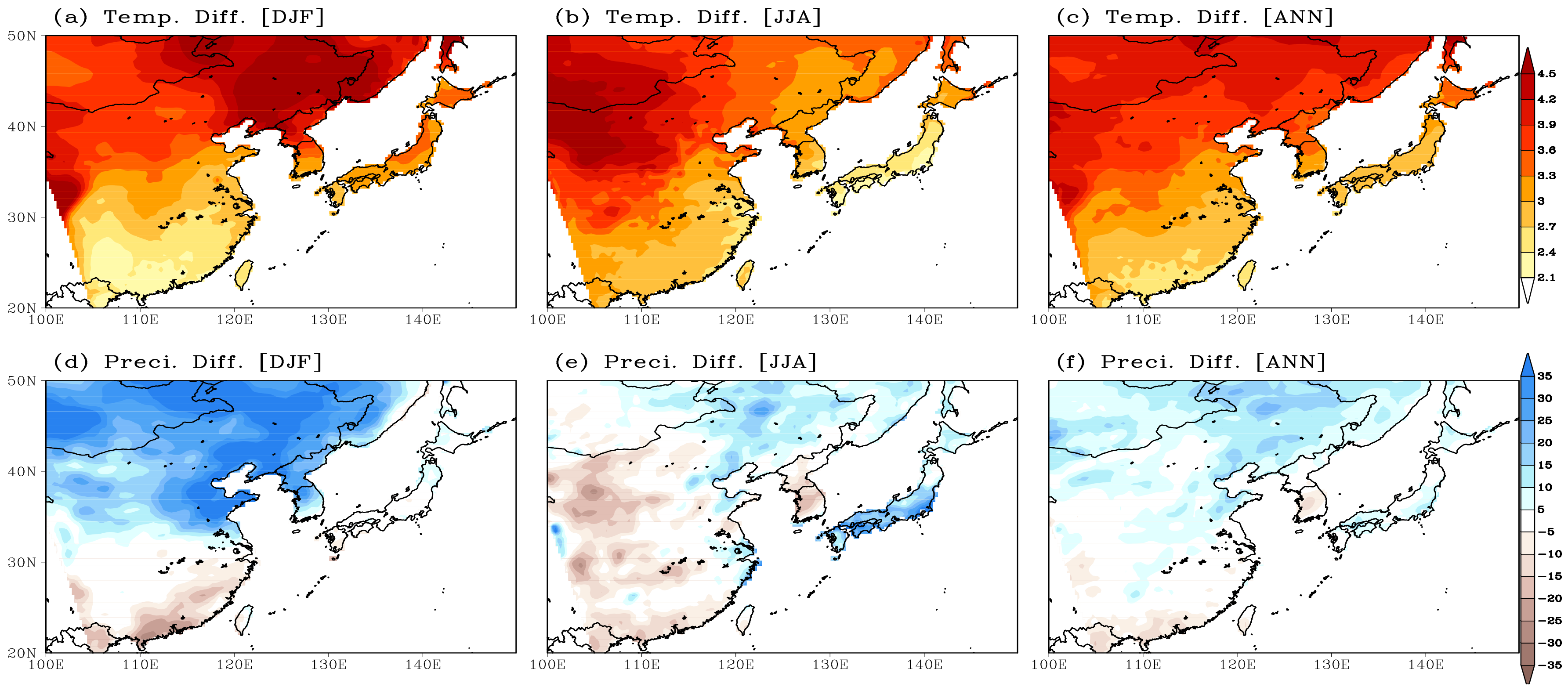
Han-Kum-Nakdong river (Korea)(740 m; Han 19678 km2,
Nakdong 15848 km2, Kum 6769 km2 drained area)

3 years RegCM-ECHAM5 A1B scenario simulation 1980/82 -2080/82

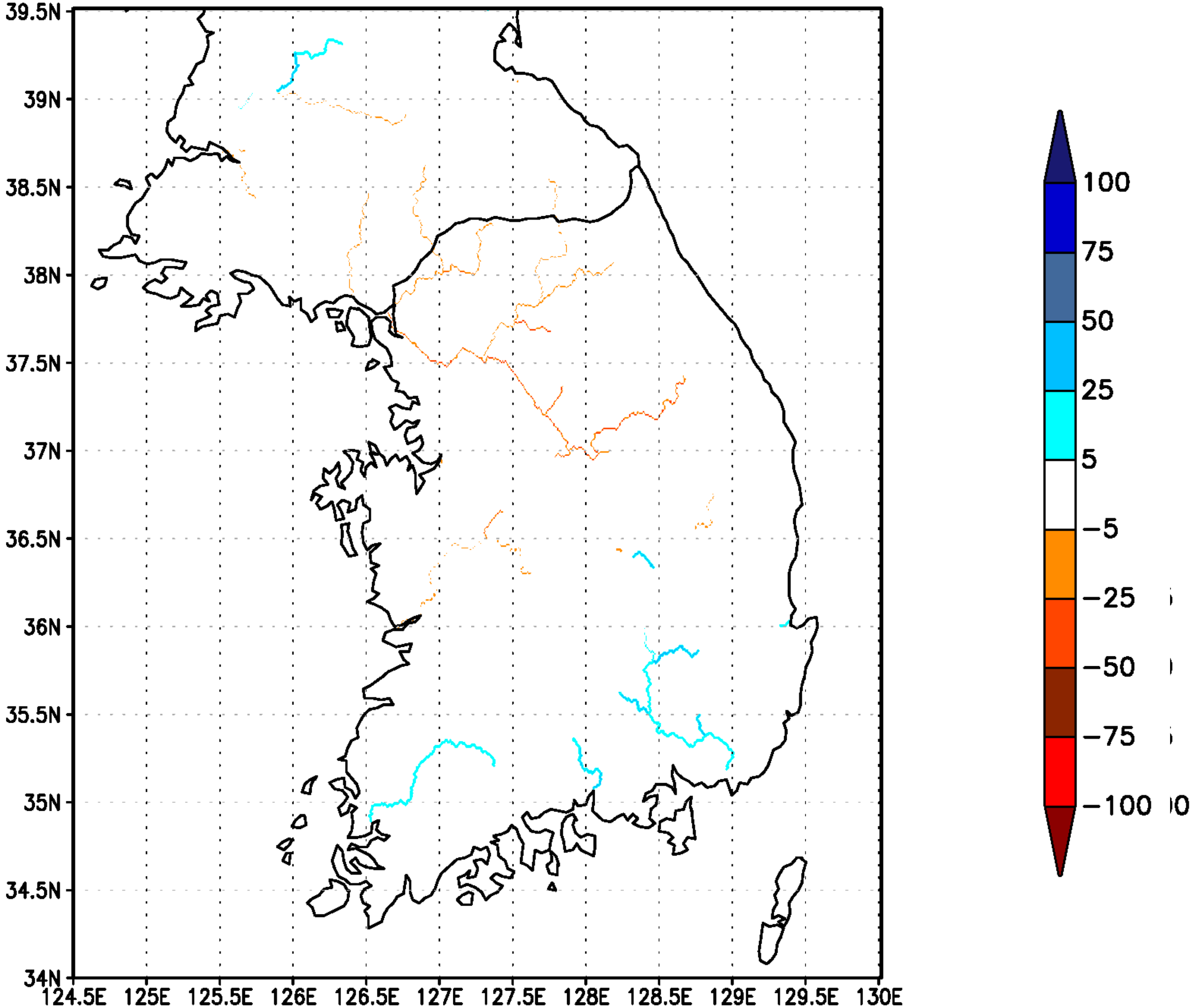
Yellow – Yangtze river (China)(5.7 km, Yellow river 360431km2,
Yangtze 564594 km2)
1 years RegCM-ECHAM5 A1B scenario simulation 1961- 2071

RegCM-ECHAM 20km A1B scenario 1950-2100

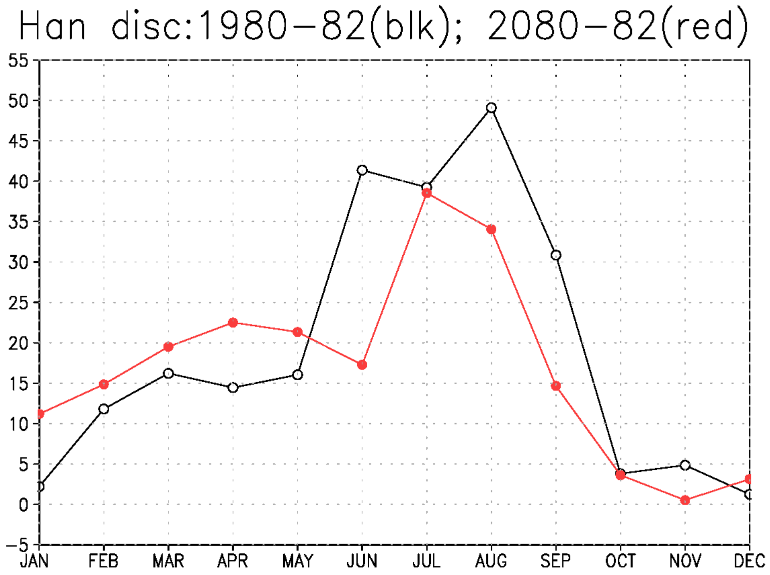
Korea



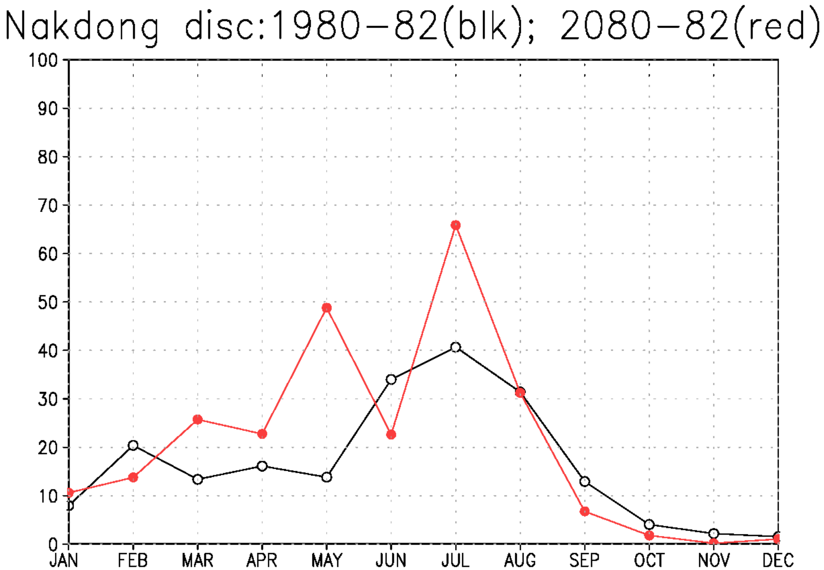
MJJAS runoff change (2080/2082)-(1980/1982)



Annual discharge cycle at the river mouth



No big change is found neither in the annual mean discharge nor in the discharge timing



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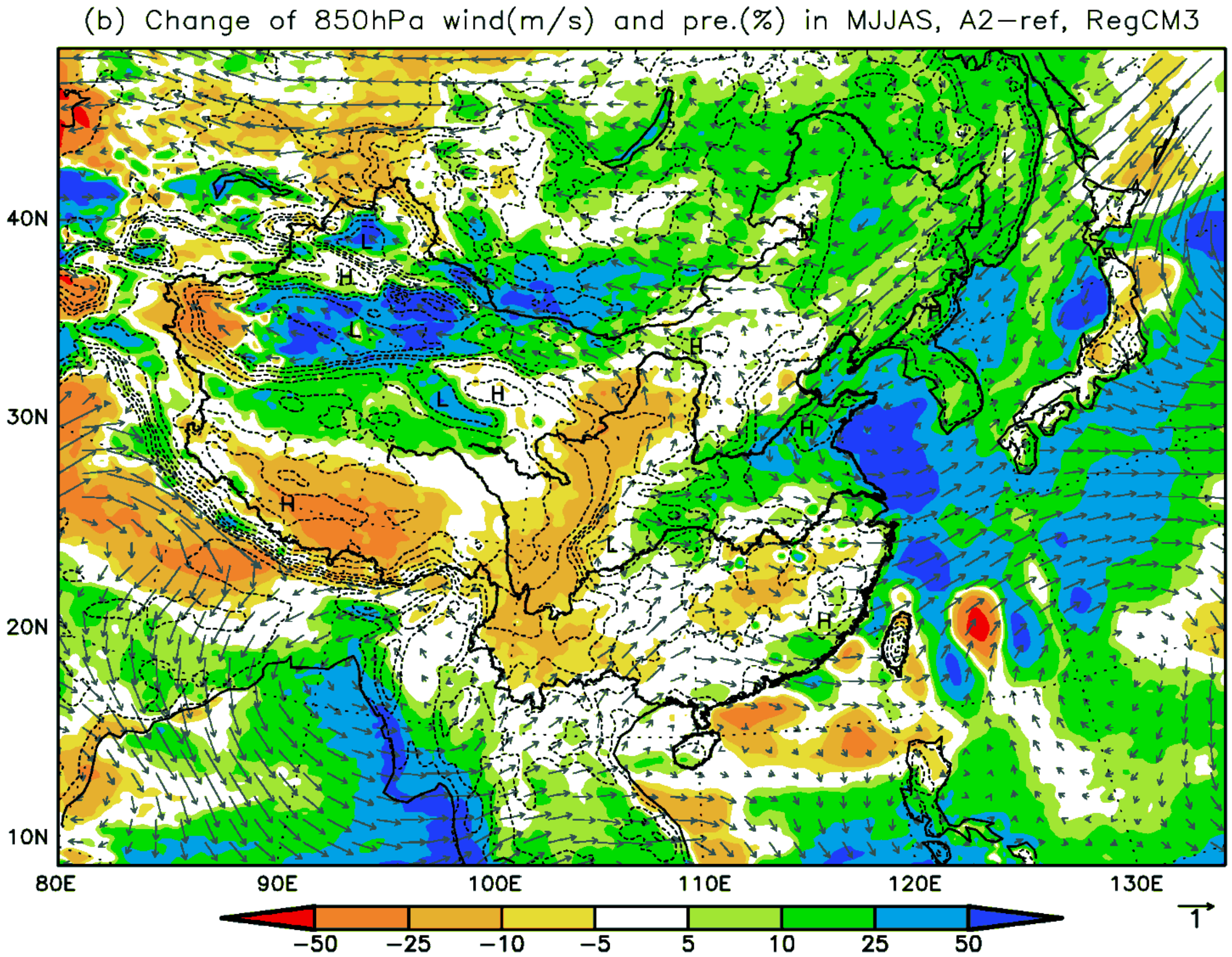
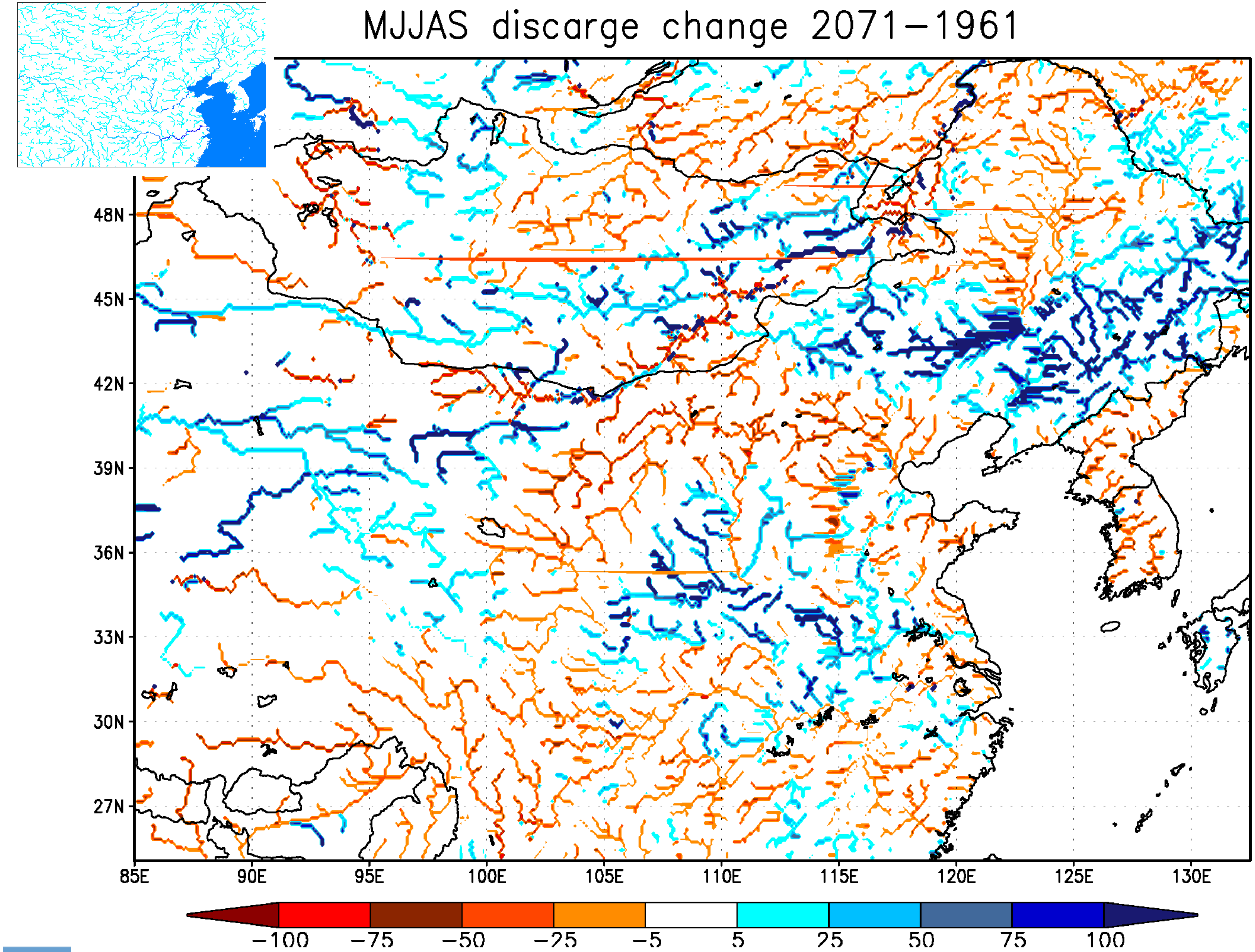
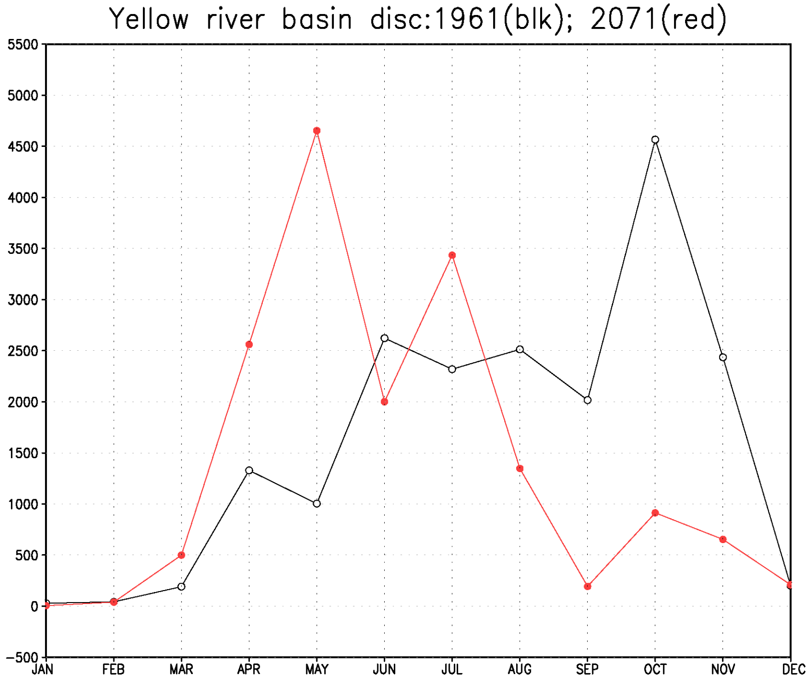
RegCM-fvGCM 20km A2 scenario 1950-2100

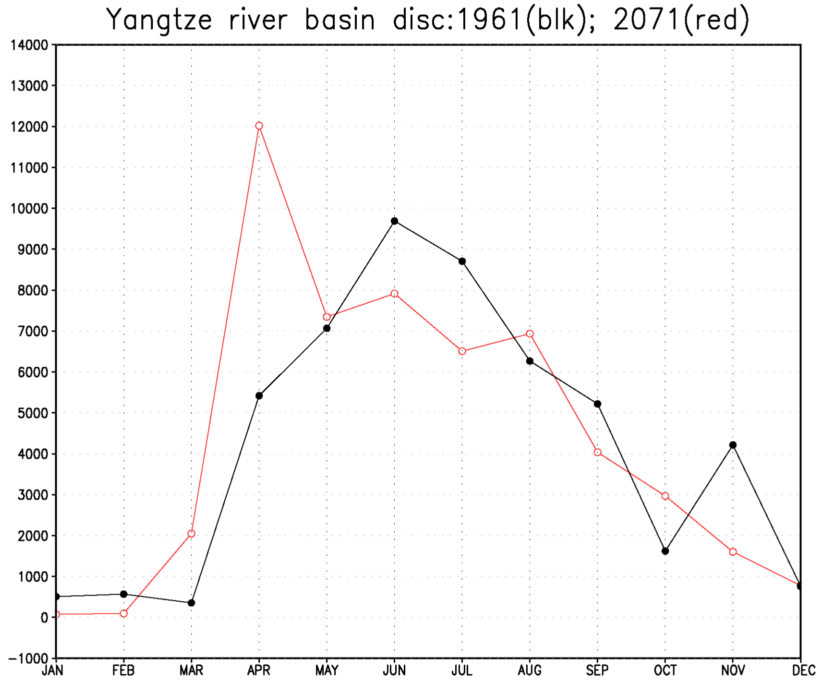
China




MJJAS discarge change 2071-1961
48N
45N
42N
39N
36N
33N
30N
27N
85E
90E
95E
100E
105E
110E
115E
120E
125E
130E
-100
-75
-50
-25
-5
5
25
50
75
100

Annual discharge at the river mouth





Shift of the OCT-NOV peak toward the early part of the summer for the Yellow river and from summer to spring for the Yangtze river

Take home messages

➢Evidence that climate change is going to impact the water resources are certain

➢Future projection with their uncertainty are going to impact regions of the world in a different way

➢We do need regional action to be ready to mitigate the consequence of climate change therefore we do need more and more the use of impact models to quantify the impact of CC

➢Work is still needed to be able to downscale the climate model signal to the typical impact model scale


Thanks!

What is a Watershed

Common Definitions:

The specific land area that drains water into a river system or other body of water.

Many Hydrologic Texts

It's the area of land that catches rain and snow and drains or seeps into a marsh, stream, river, lake or groundwater.

The rest of them

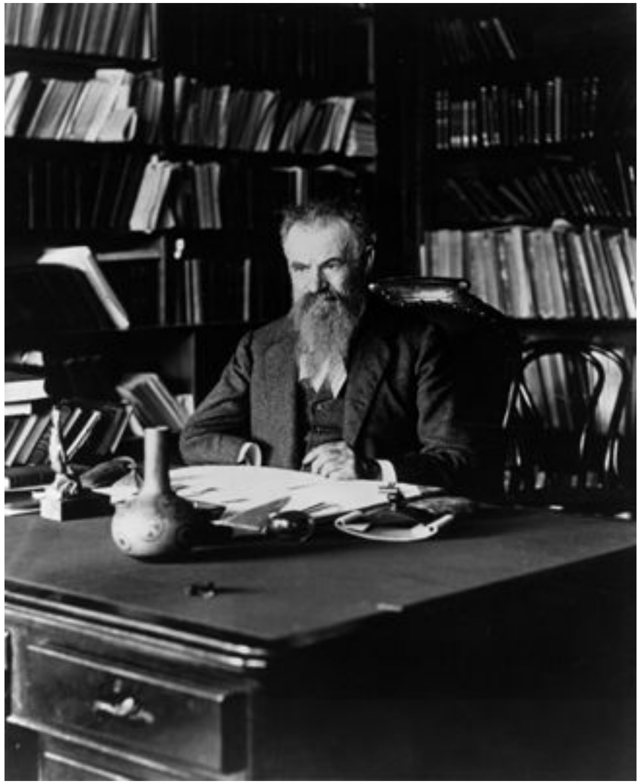
What is a Watershed “ Another Definition”

Watersheds are **nature's** way of dividing up the **landscape**. Rivers, lakes, estuaries, wetlands, streams, even the oceans can serve as catch basins for the land adjacent to them. Ground water aquifers serve the same purpose for the land above them.

The actions of people who live within a watershed affect the health of the waters that drain into it.

EPA. Surf Your Watershed

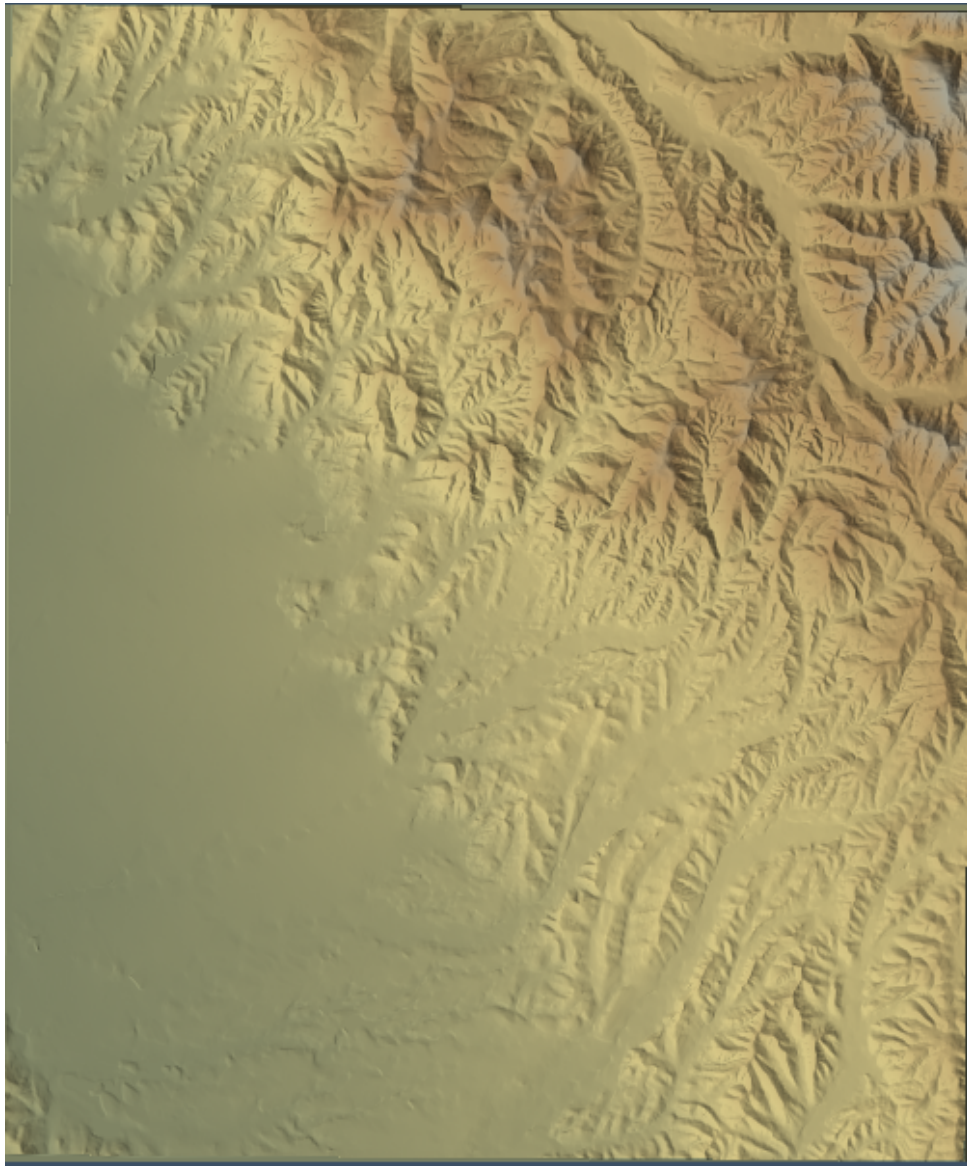
What is a Watershed? " the one I like"



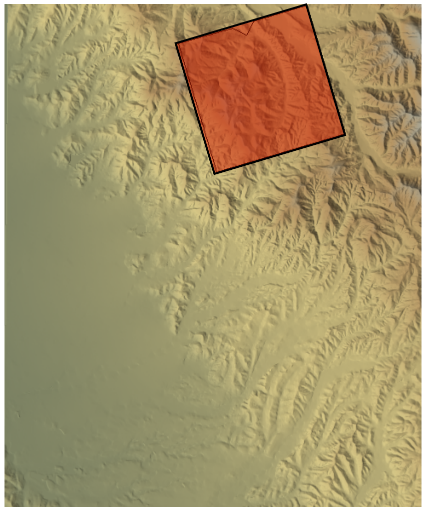
"that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of the community."

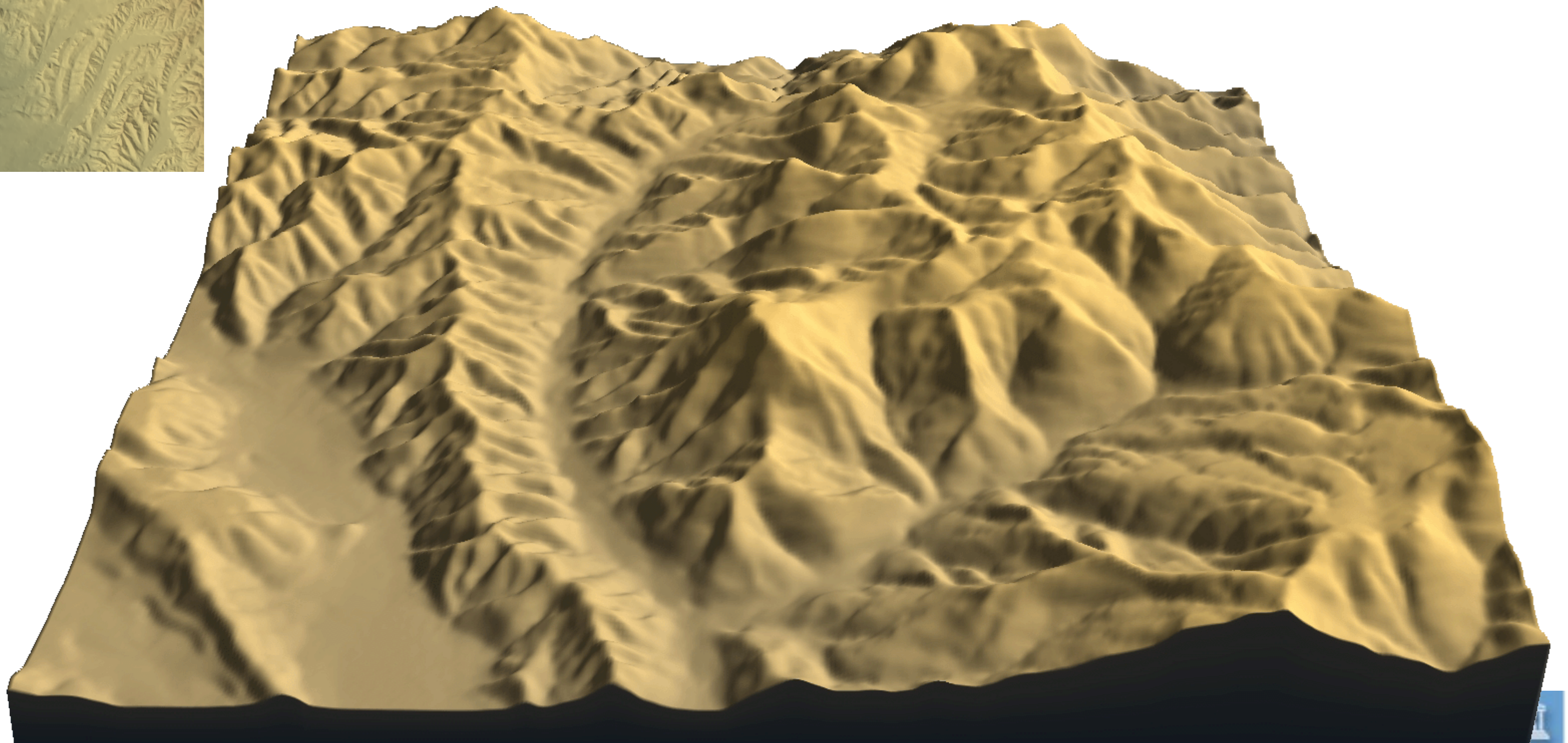
John Wesley Powell -- scientist, geographer, and leader of the first expedition through the Grand Canyon in 1869.

Nature's Way → Terrain

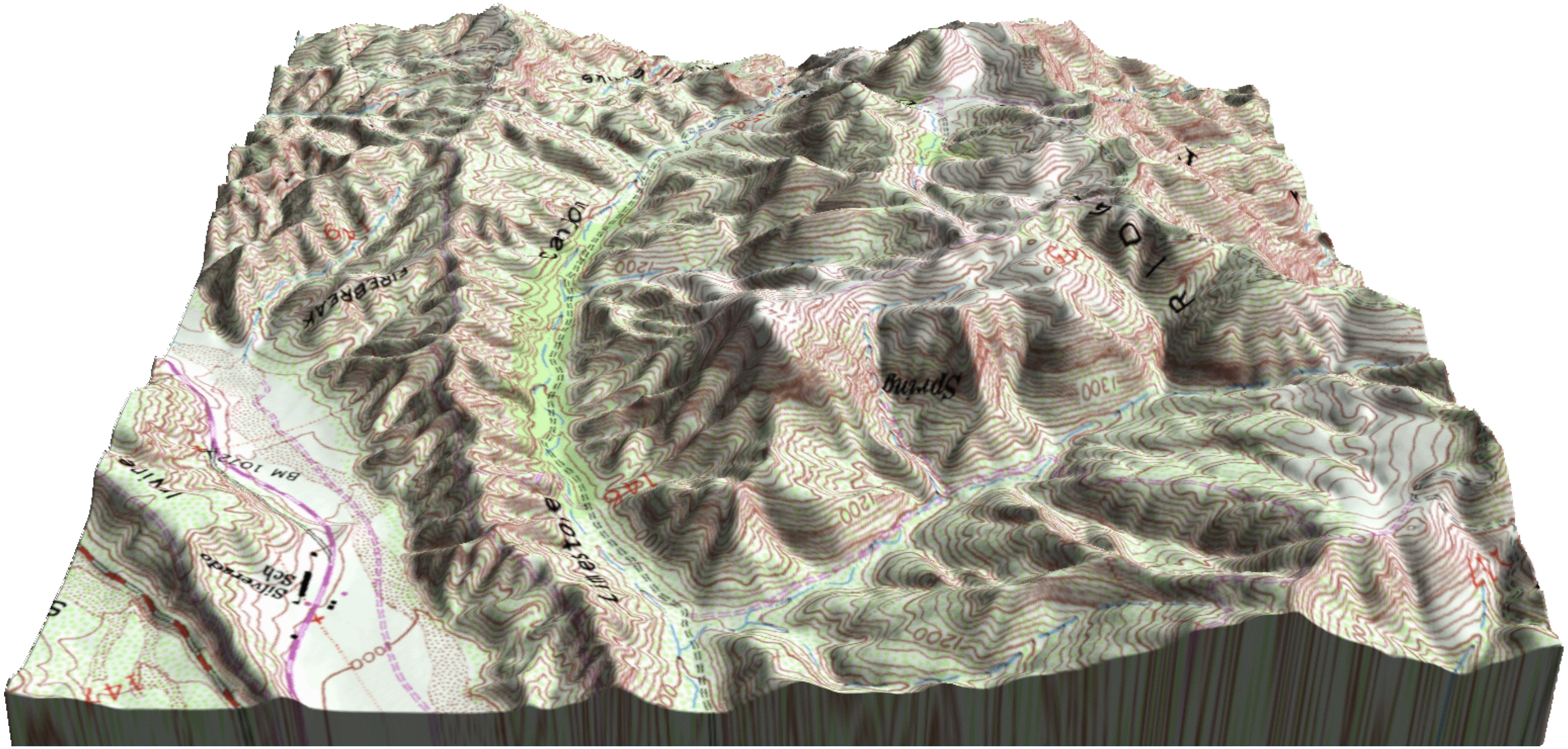


Nature's Way → Terrain

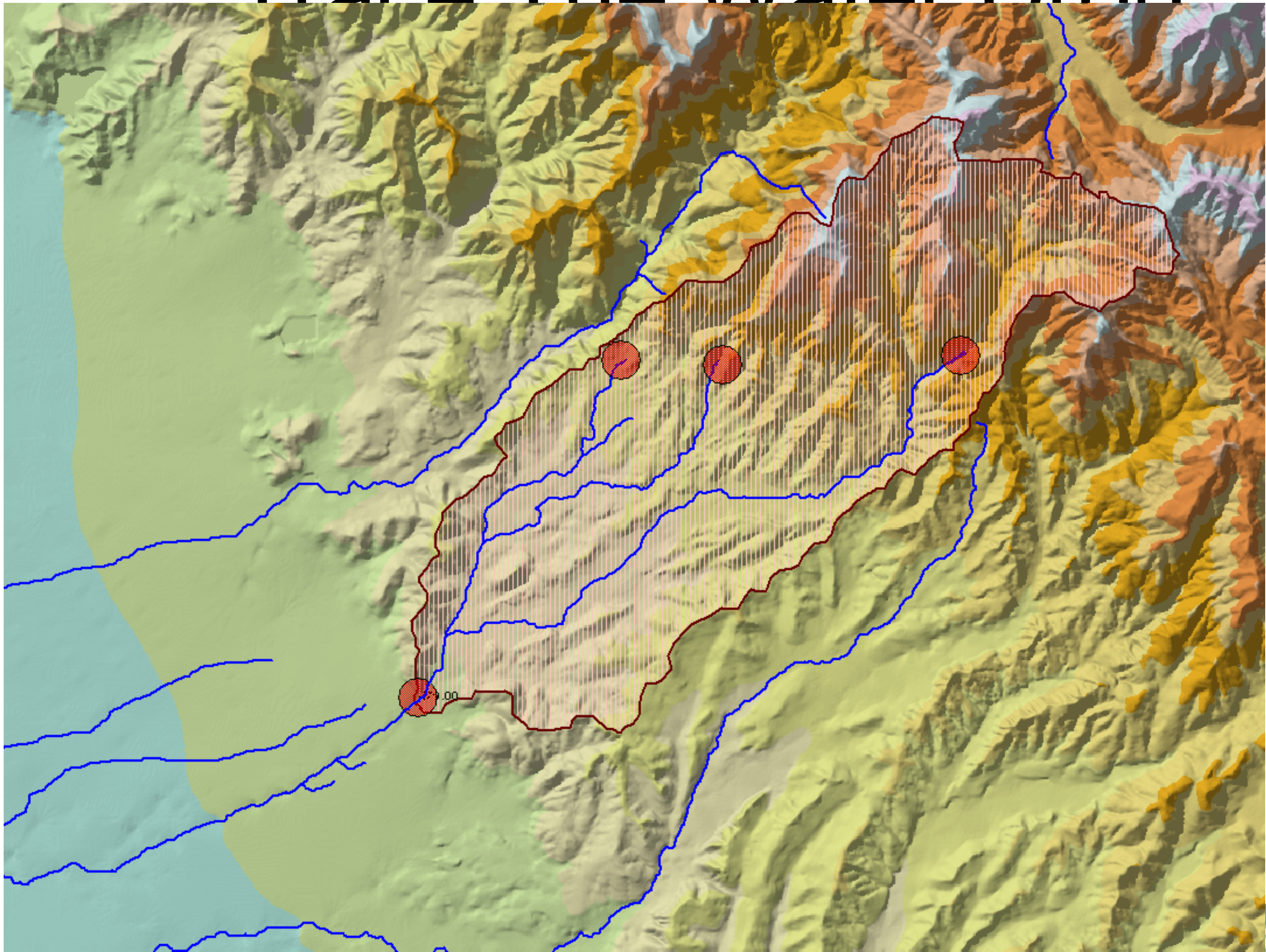




A Close-up

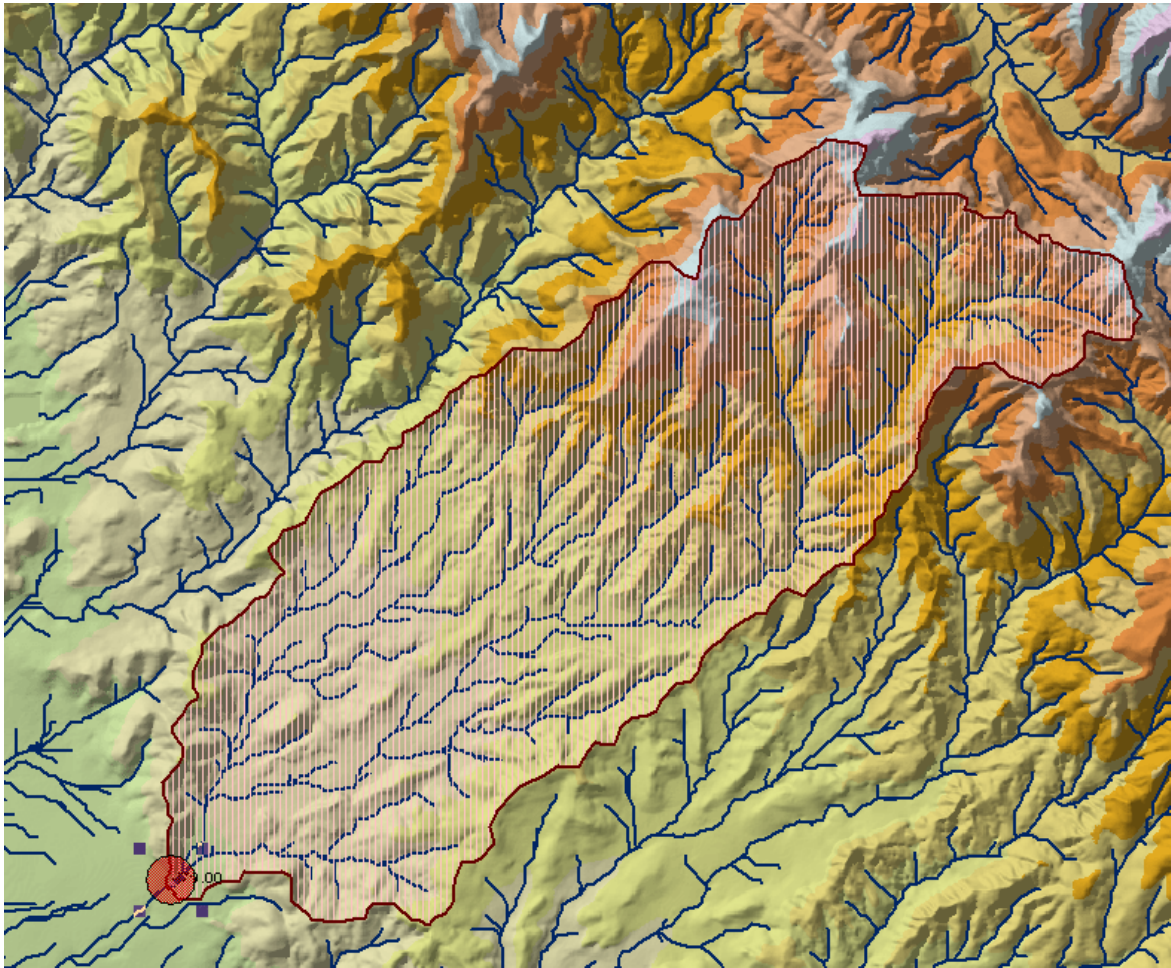


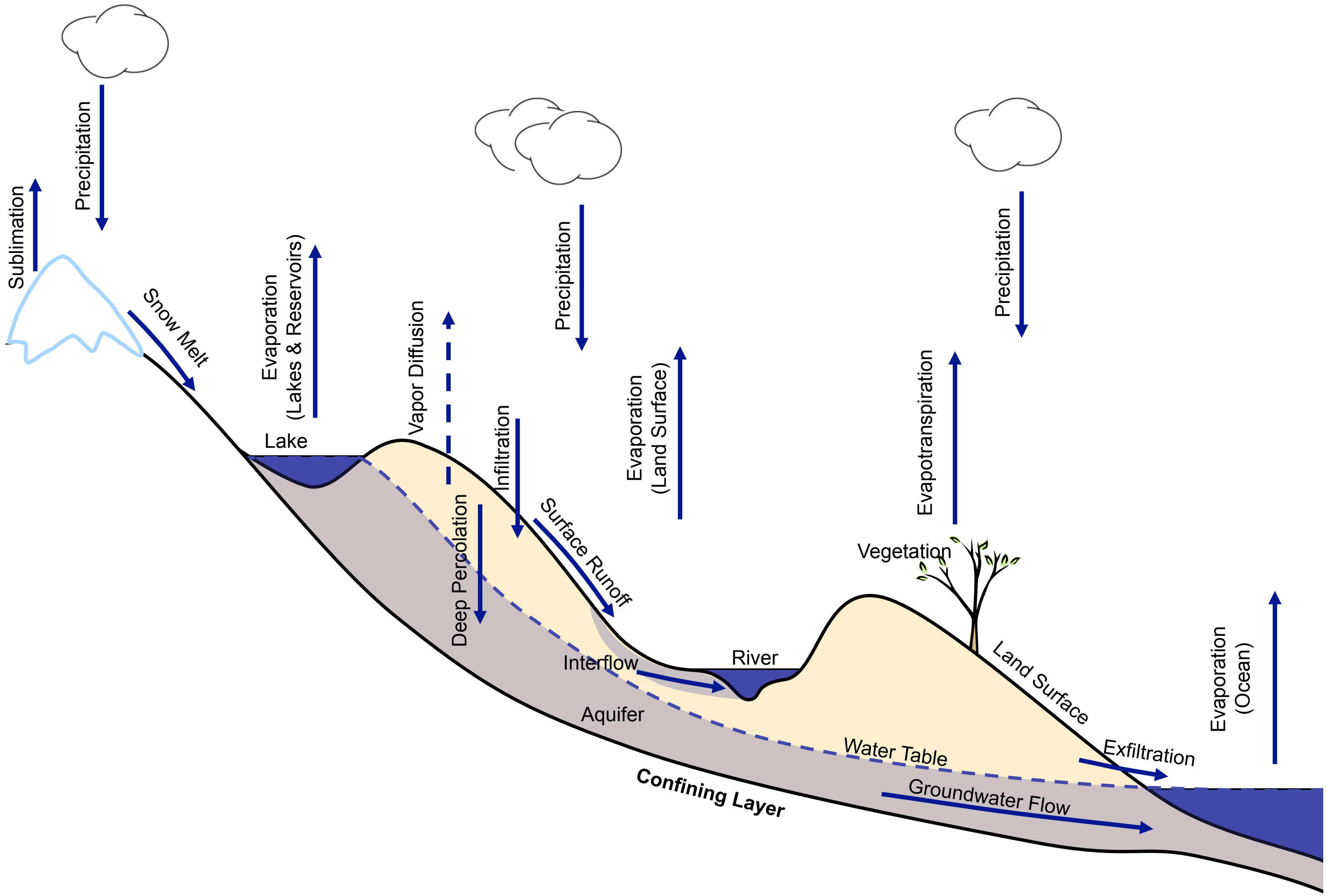
Trace The Water Drop



The Watershed

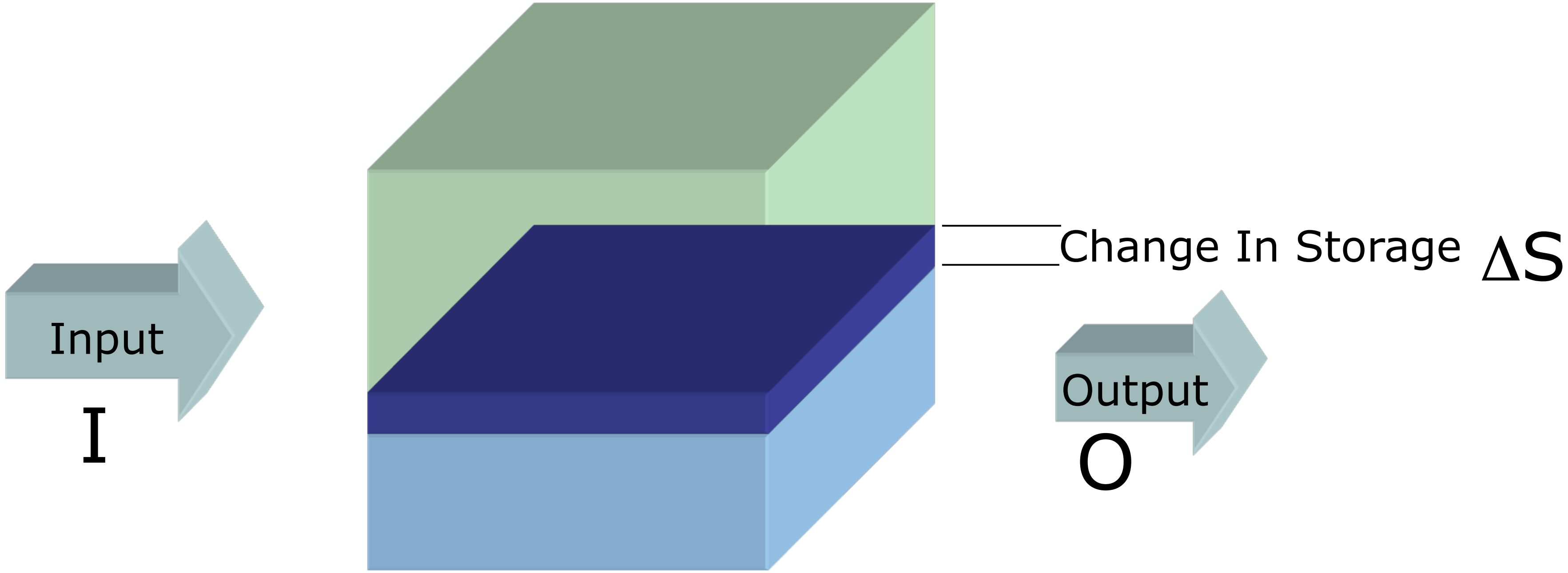
Area km2	12.78
Perimeter km	19.344
Min Elevation m	478.00
Max Elevation m	1756.00
Mean Elevation	930.34
Max Flow Length	8.878




Sublimation
Precipitation
Snow Melt
Evaporation
(Lakes & Reservoirs)
Lake
Vapor Diffusion
Precipitation
Infiltration
Deep Percolation
Surface Runoff
Evaporation
(Land Surface)
Evapotranspiration
Precipitation
Vegetation
River
Interflow
Aquifer
Land Surface
Exfiltration
Evaporation
(Ocean)
Water Table
Groundwater Flow
Confining Layer

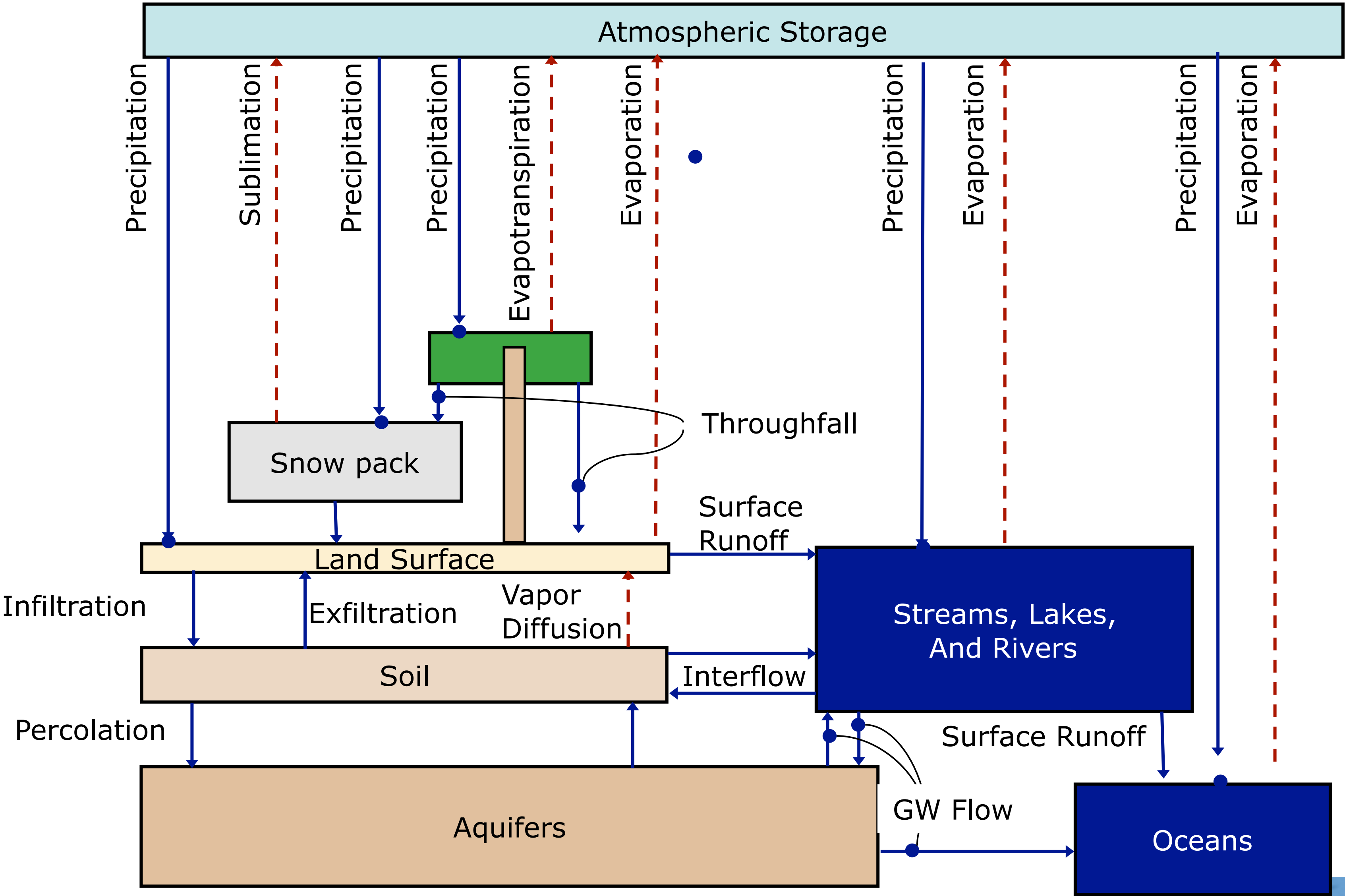
Ponce, 1989

Fundamental Law

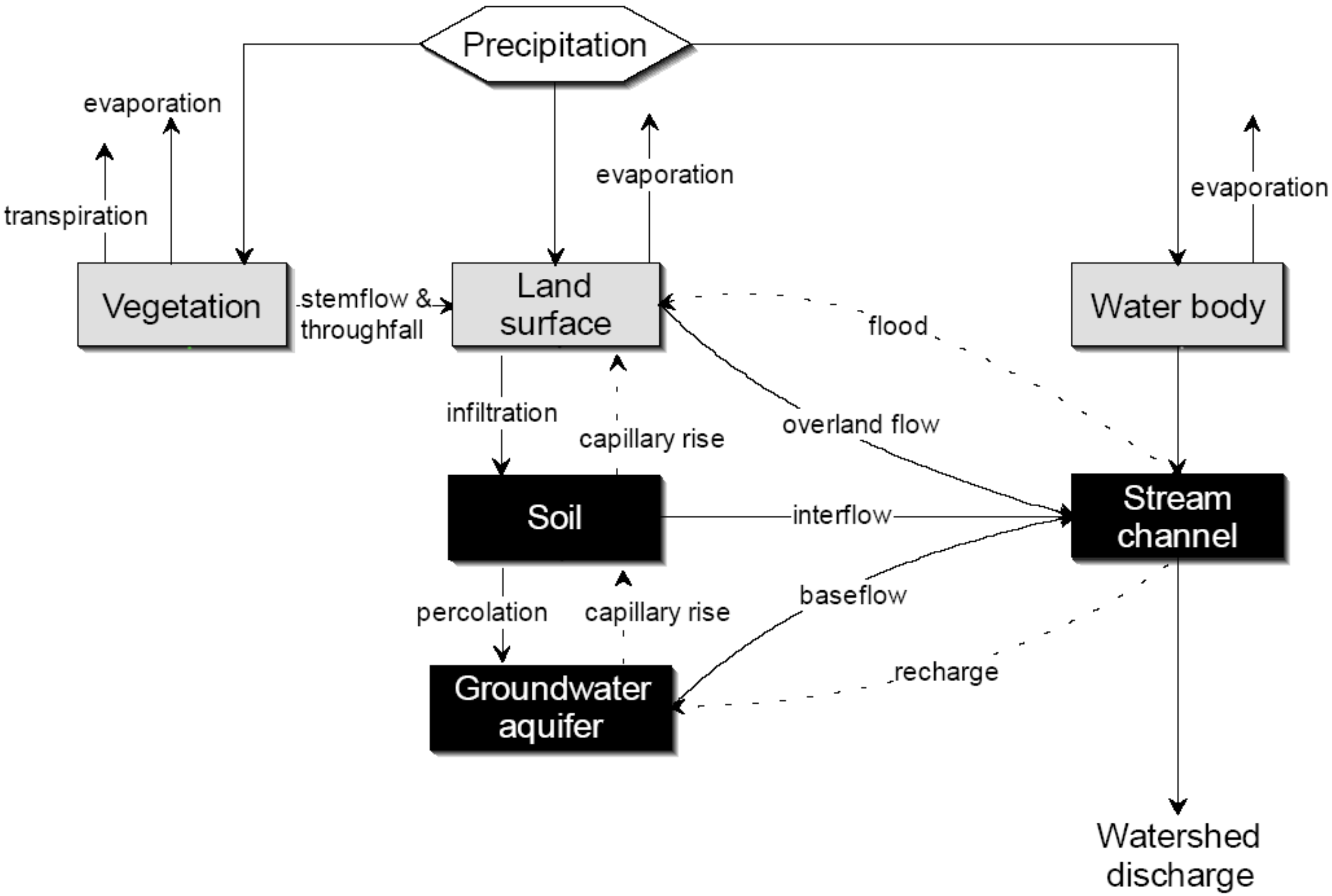


$$I - O = \Delta S$$

The Water Cycle



System representation



HEC's System representation