Effect of model scale on the assessment of climate change impact on river flow – a case study for the Narew (Poland)

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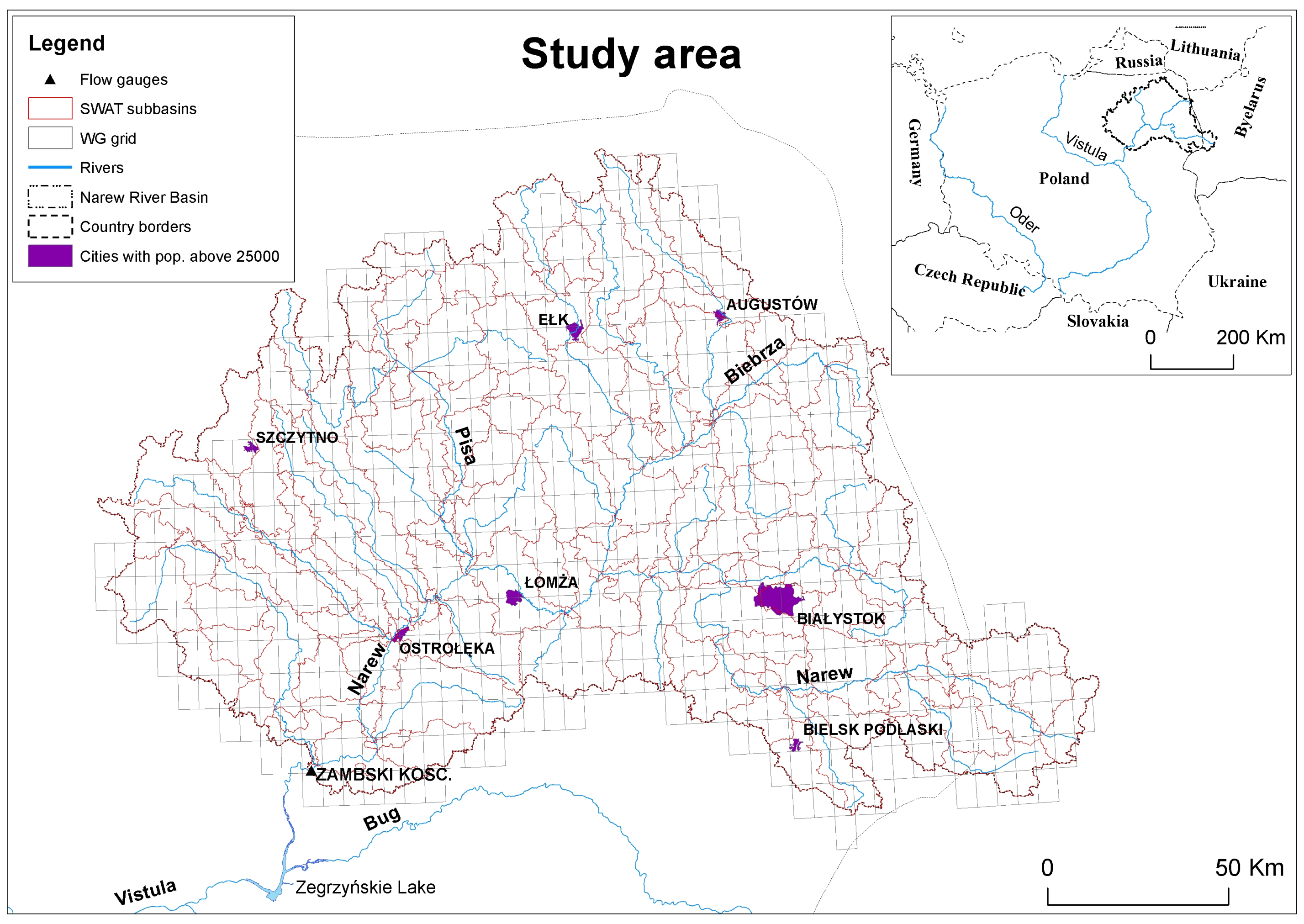
Introduction

The objective of this study has been to analyse the effect that the hydrological model scale has on the assessment of climate change impact on river flow. By climate change impact we understand here the scenarios of precipitation (P) and temperature (T) change from three selected General Circulation Models (GCMs). This quantification has been done by comparing the results extracted from the global **WaterGAP** (Water: Global Assessment and Prognosis, **WG**) model for **the Narew basin (NB**) with the results from the locally-applied **SWAT** (Soil & Water Assessment Tool) model customised for the study area. Hydrological indicators representing **mean and extreme monthly flows** as well as indicators representing model consistency were evaluated.

Comparison of hydrological models

The table below summarises the modelling philosophies and input data types used by selected models. SWAT is generally more physically-based and therefore much more parametrised than WG.

	Aspect	SWAT	WG
Modelling philosophy	Basic unit	Hydrologic Response Unit (mean area 24 km^2)	5" by 5" grid cell (area 54 km^2)
	PET	Penman-Monteith method	Priestley-Taylor method
	AET	evaporation from canopy + sublimation + plant water uptake + soil evaporation	evaporation from canopy + sublimation + evapotranspiration vegetated soil
	Snow melt	degree-day method	degree-day method
	Surface runoff	modified SCS curve number method	HBV method
	Redistribution in soil	storage routing method between up to 10 soil layers	no redistribution, one soil layer
	Groundwater storage	two groundwater storages (shallow unconfined and deep confined)	one groundwater storage
	Baseflow	recession constant method	linear storage equation
	Flood routing	variable storage coefficient method	linear storage equation
Input data	Drainage topology	based on 30m resolution DEM and stream network map	based on the global drainage direction map DDM5
	Land use map	Corine Land Cover 2000	Corine Land Cover 2000
	Soil map	based on ca. 3400 benchmark soil profiles in the Narew basin	FAO
	Climate	daily data from 15-20 climate stations in the basin	monthly data from the CRU 10' resolution global dataset



Study area

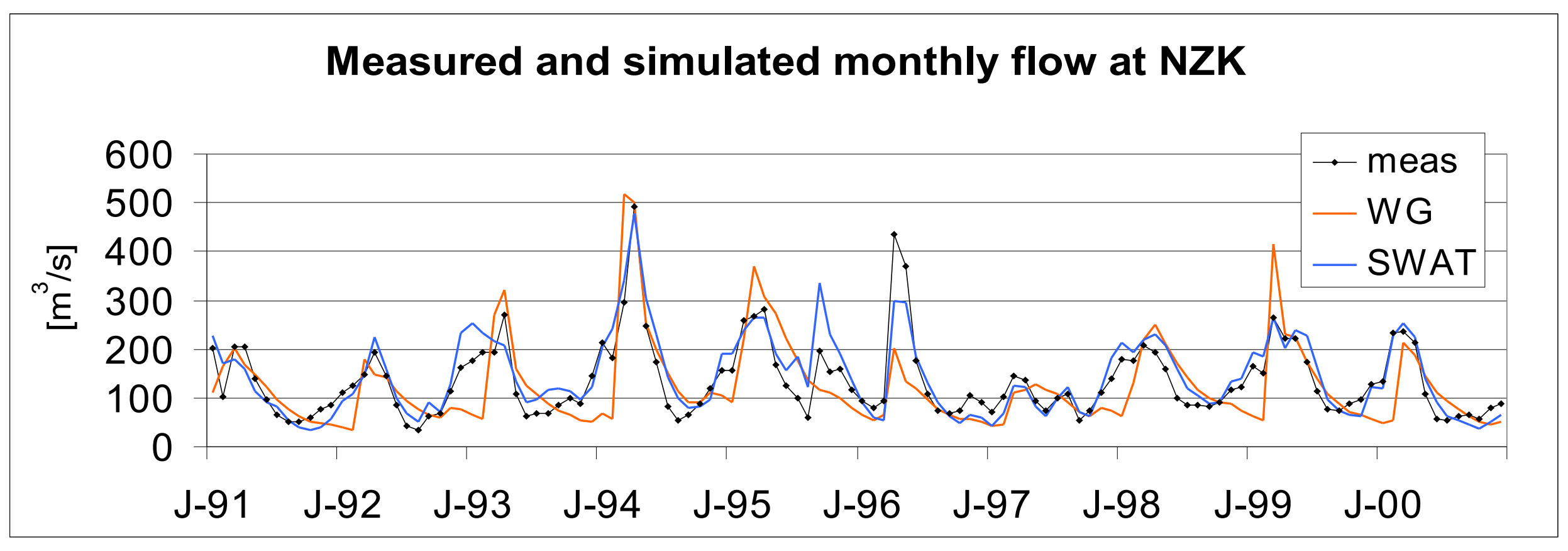
The part of the NB situated in NE Poland, occupying ca. **28 000 km^2** upstream from Zambski Kościelne gauge (NZK), was selected as the study area. The NB is a good area for purely hydrological research since it is only moderately impacted by human activity. There is only one city with population above 100 000 inhabitants (Białystok) whose water abstractions are significant. Water use for industry and agriculture is also not very harmful to the basin's water resources.

Evaluation of models for the baseline period

The table below presents the goodness-of-fit measures for SWAT and WG for the **baseline** period (**1976-2000**) and the figure presents the measured and simulated hydrograph of the Narew at Zambski for the time slice 1991-2000.

	Q_{meas}		Q_{SWAT}		Q_{WG}		NSE		R^2		Bias	
Gauge	Mean	Sd	Mean	Sd	Mean	Sd	SWAT	WG	SWAT	WG	SWAT	WG
NZK	144	82.6	142	77.3	121	80.6	0.72	0.35	0.73	0.45	1%	16%

Note: Sd – Standard deviation, NSE – Nash-Sutcliffe Efficiency



- **Performance of SWAT** expressed numerically by NSE and R^2 is **better than** of **WG** (since WG was not tuned in the NB while SWAT was)
- WG underestimates mean flow, SWAT well preserves water balance
- WG tends to continuously decrease flow from spring peaks until late winter whereas measured hydrographs are more variable (including e.g. summer freshets)

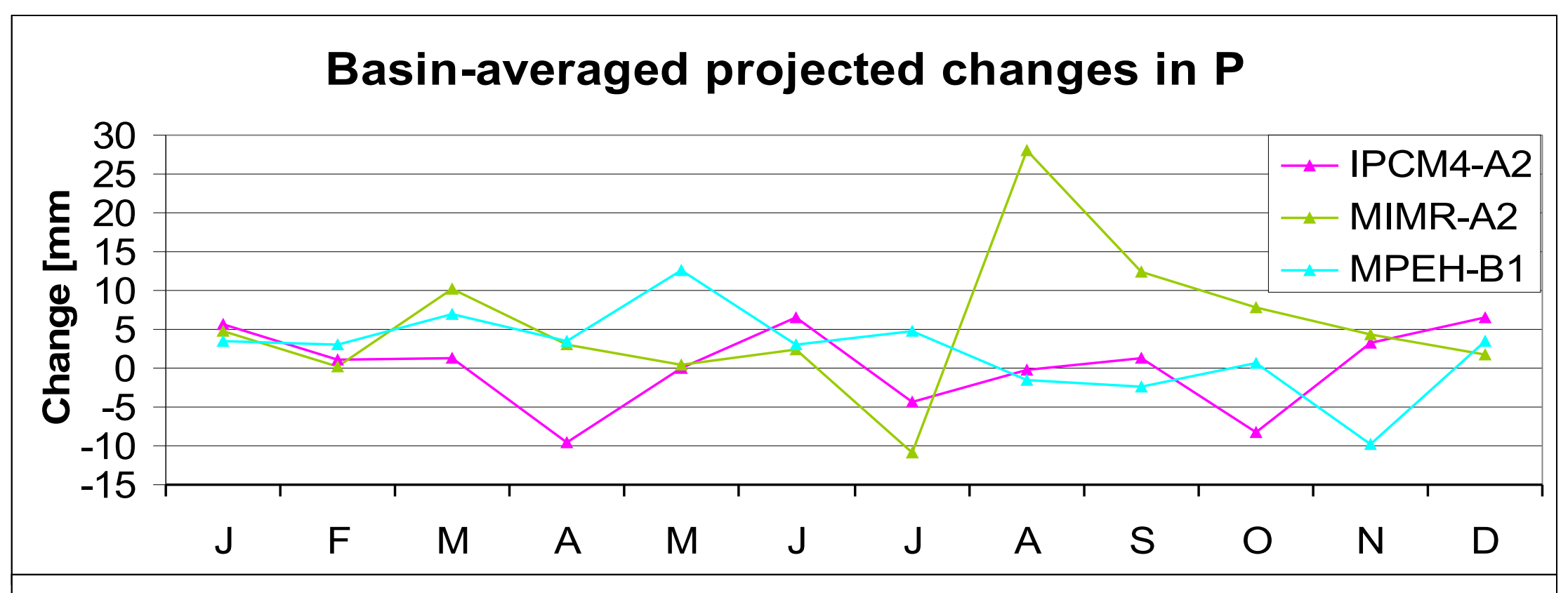
Climate change models and data

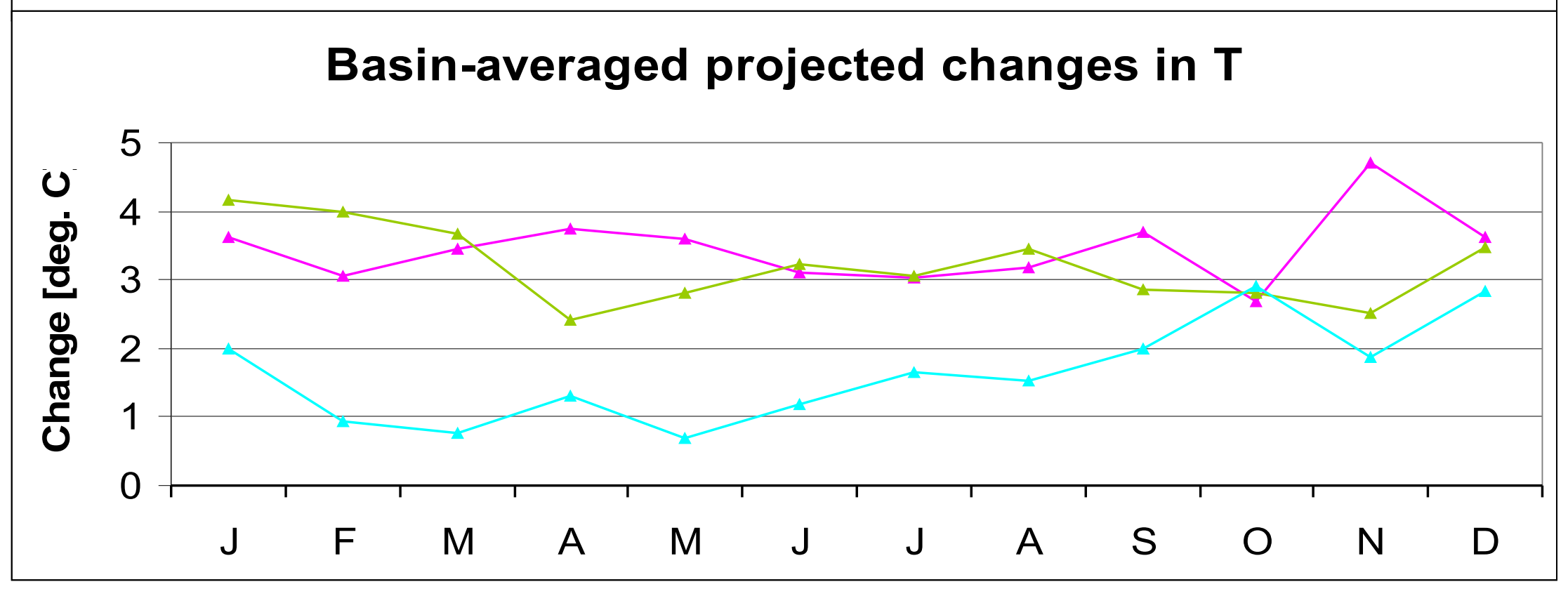
Three combinations of GCMs and SRES scenarios were used, which represent a huge range of variability of GCM output were used (see figure below):

(1) The IPSL-CM4 model from the Institute Pierre Simon Laplace, France; A2 scenario (**IPCM4-A2**) with high T increase and low P increase/decrease ("warm&dry");

(2) The MICRO3.2 model from the Center for Climate System Research, University of Tokyo, Japan; A2 scenario (**MIMR-A2**) with high T increase and high P increase or low decrease ("warm&wet");

(3) The ECHAM5/MPI-OM model from the Max-Planck Institute for Meteorology, Germany; B1 scenario (**MPEH5-B1**) with low T increase and an average P change ("moderate").





The GCM outputs for the time periods **2040-69** (representing the 2050s) and 1970-99 were used in this study. The **delta change** method was applied to derive future time series for T and P (WG and SWAT accordingly).

Results

Mean monthly flow (**Q_{mean}**) representing average conditions and monthly **Q_{10}** and **Q_{90}**, representing high and low flows respectively were used to evaluate the impact of climate change on river flow. Indicators for each of these variables were calculated as percent deviations of scenario runs from the baseline run (see figure below to the right).

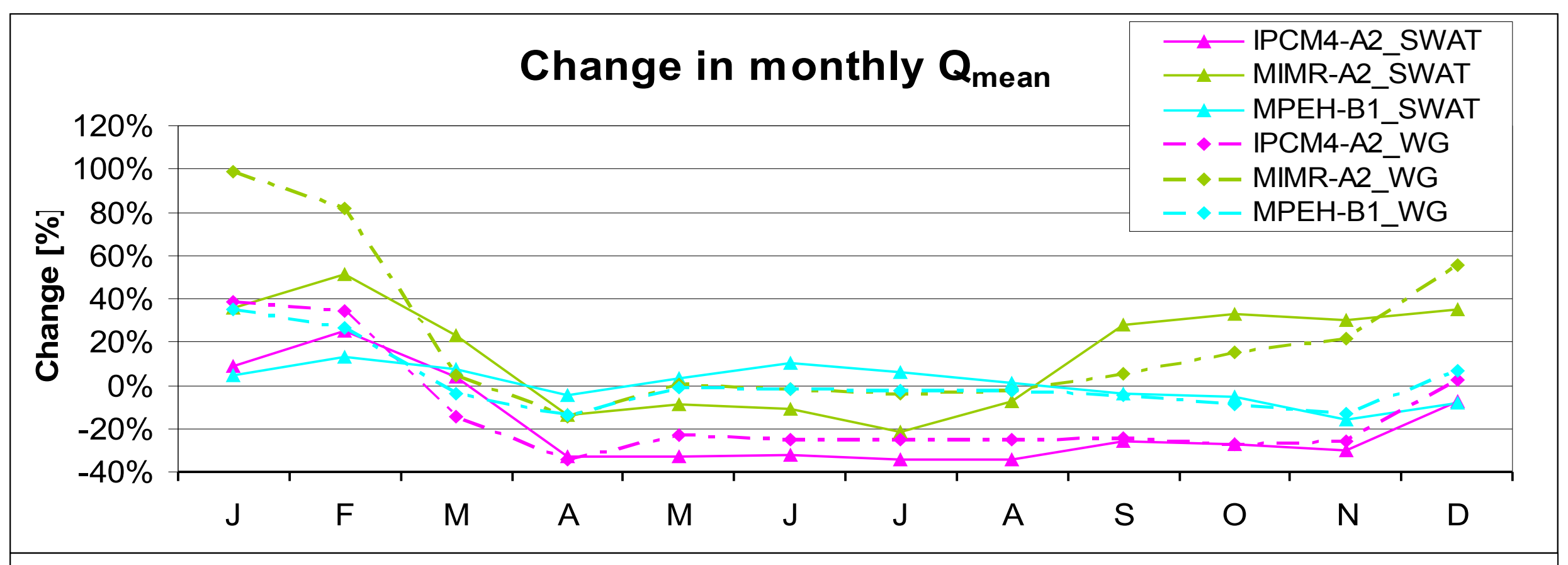
Finally, **model consistency indicators** for the month *i*, ***MCI_i***, were calculated:

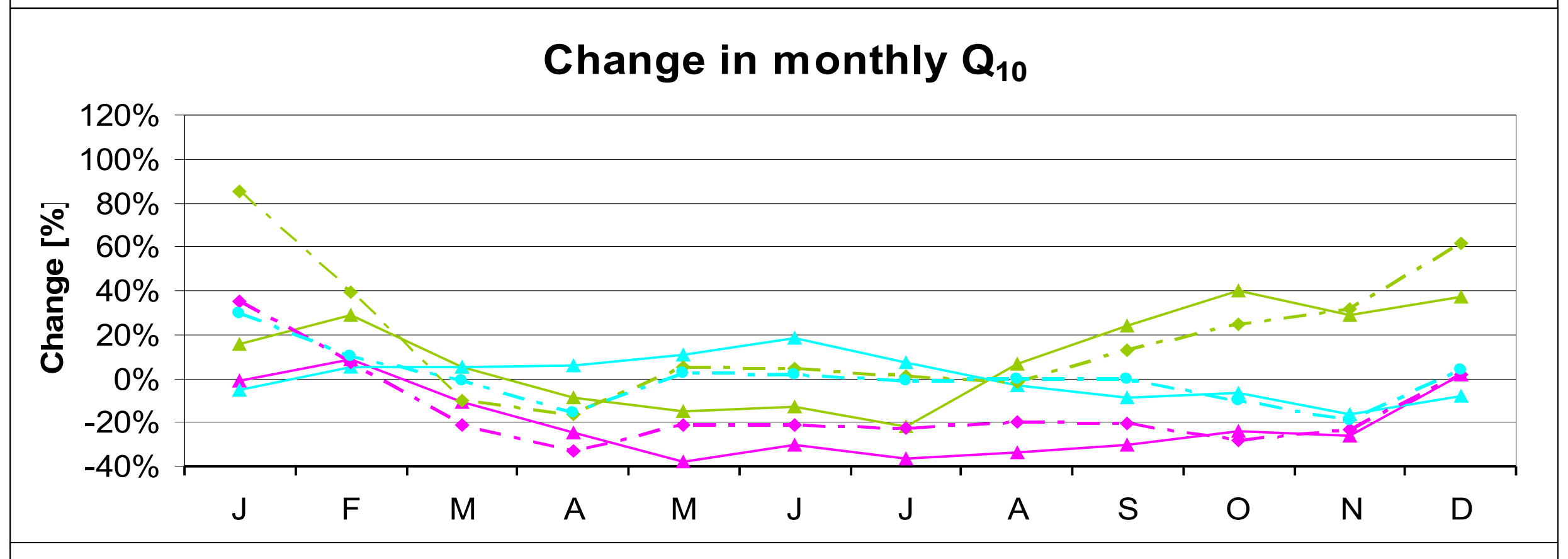
$$MCI_i = |Ind_{SWAT,i} - Ind_{WG,i}|$$

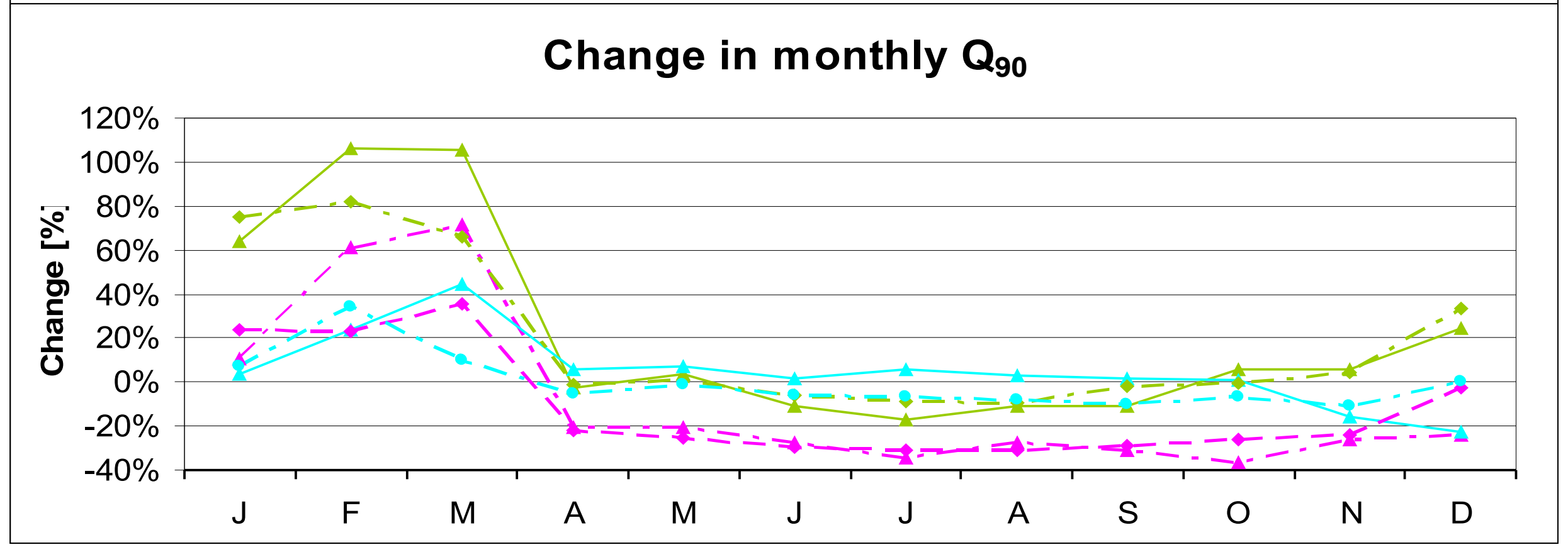
where $Ind_{SWAT,i}$, $Ind_{WG,i}$ – hydrological indicators (percent deviation in Q_{mean}, Q_{10} or Q_{90}) for SWAT and WG respectively for the month *i*. *MCI* measures the consistency of SWAT and WG in the assessment of climate change impact on a given characteristics of flow regime. The lower this value, the stronger model consistency (see figure below to the left).

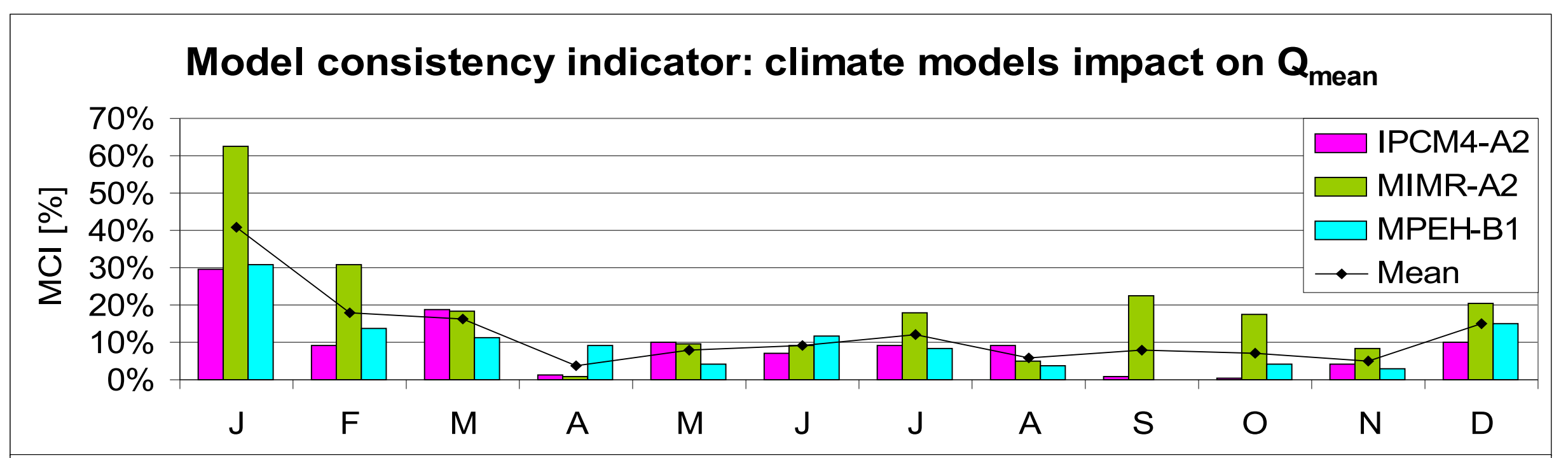
Discussion

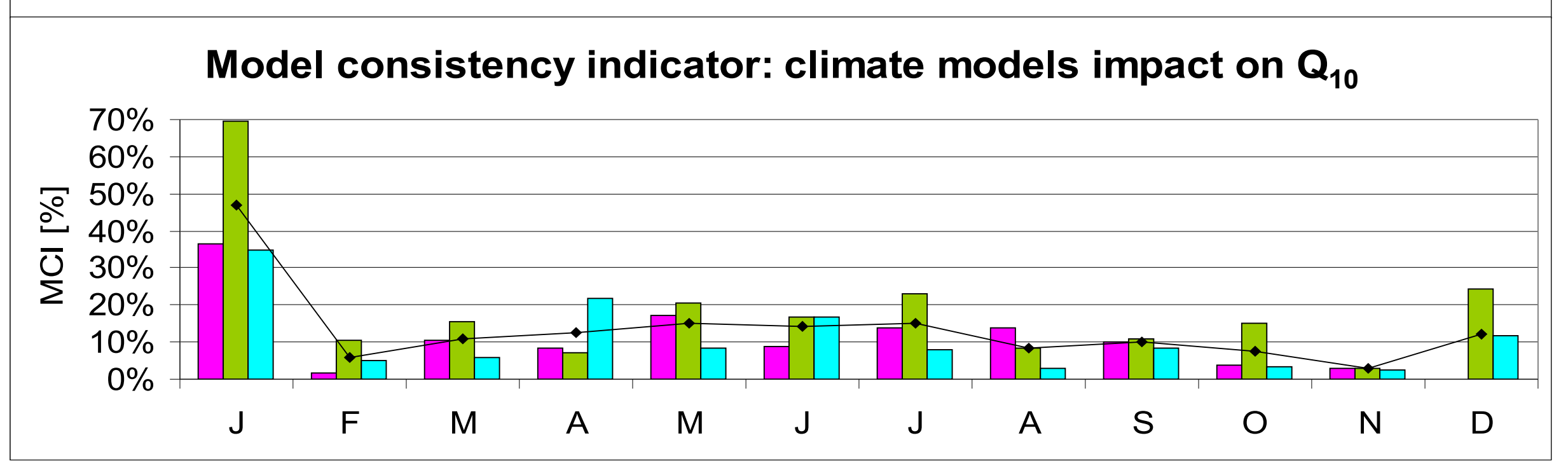
- both hydrological models are sensitive to the climate change signal, whose impact on flow regime of the Narew tends to be **the highest in winter**, regardless the climate model, the hydrological model and the type of hydrological indicators
- the impact on mean and high flows is similar, on low flows not
- climate models forcings have variable effect on the river flow:
  - ➔ IPCM4-A2: medium decrease in flow indicators during most of the year (between -40 and -20% from April to November) apart from winter (uneven response);
  - ➔ MIMR-A2: large increase in flow indicators in autumn and winter (up to 60-100% for Q_{90} in winter) and moderate change and low decrease in the rest of the year;
  - ➔ MPEH-B1: moderate effects, increase more likely than decrease (from January to March changes of -5 to 45% for all the indicators).

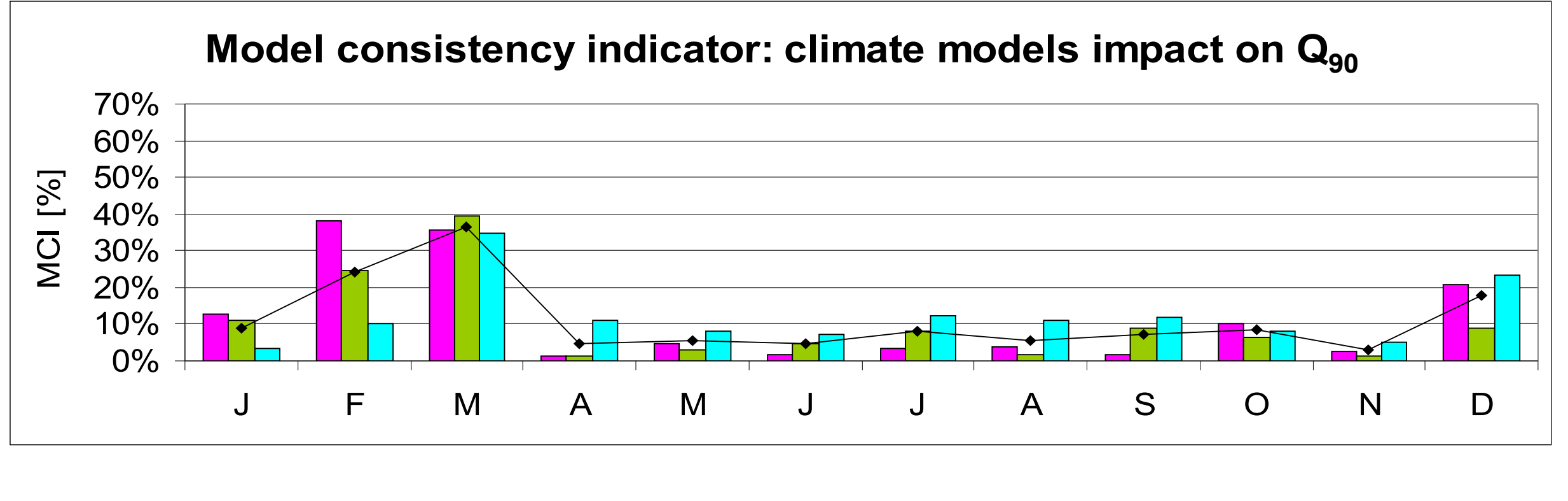












- the mean value of all the 108 calculated *MCI*s (3 climate models x 3 flow indicators x 12 months) is 12%;
- there is **strong seasonal variability** in the consistency of SWAT and WG in the assessment of climate change impact on flow regime. The monthly variability of all the *MCI*s for all the models from April to November is relatively low. Model inconsistency gets very high (above 30% for all the climate models) for **mean and high flows in January** and for **low flows in March**, possibly due to differences in snow melt description.

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