Assessment on the impact of climate change on water resource at watershed scale: a case study in River Xiangxi

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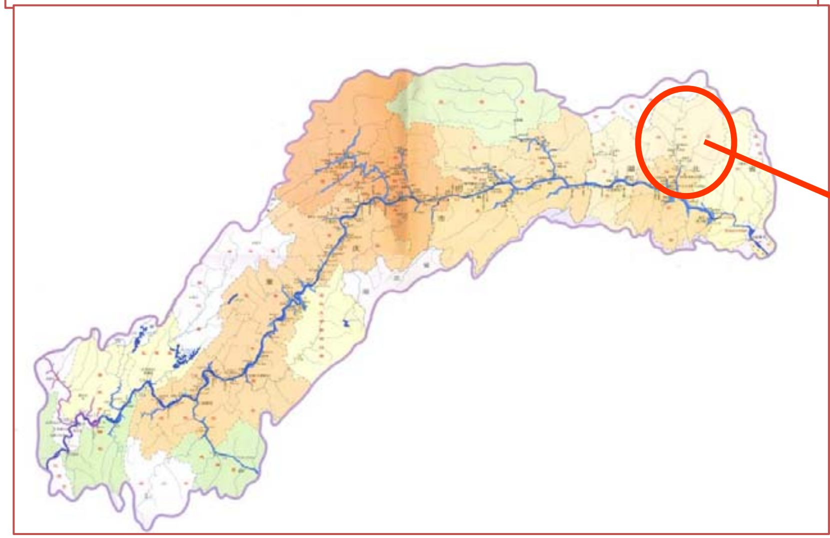
Outline

1. Study Area
2. Hydrological modelling based SWAT
3. Climate Change Impact
4. Summary

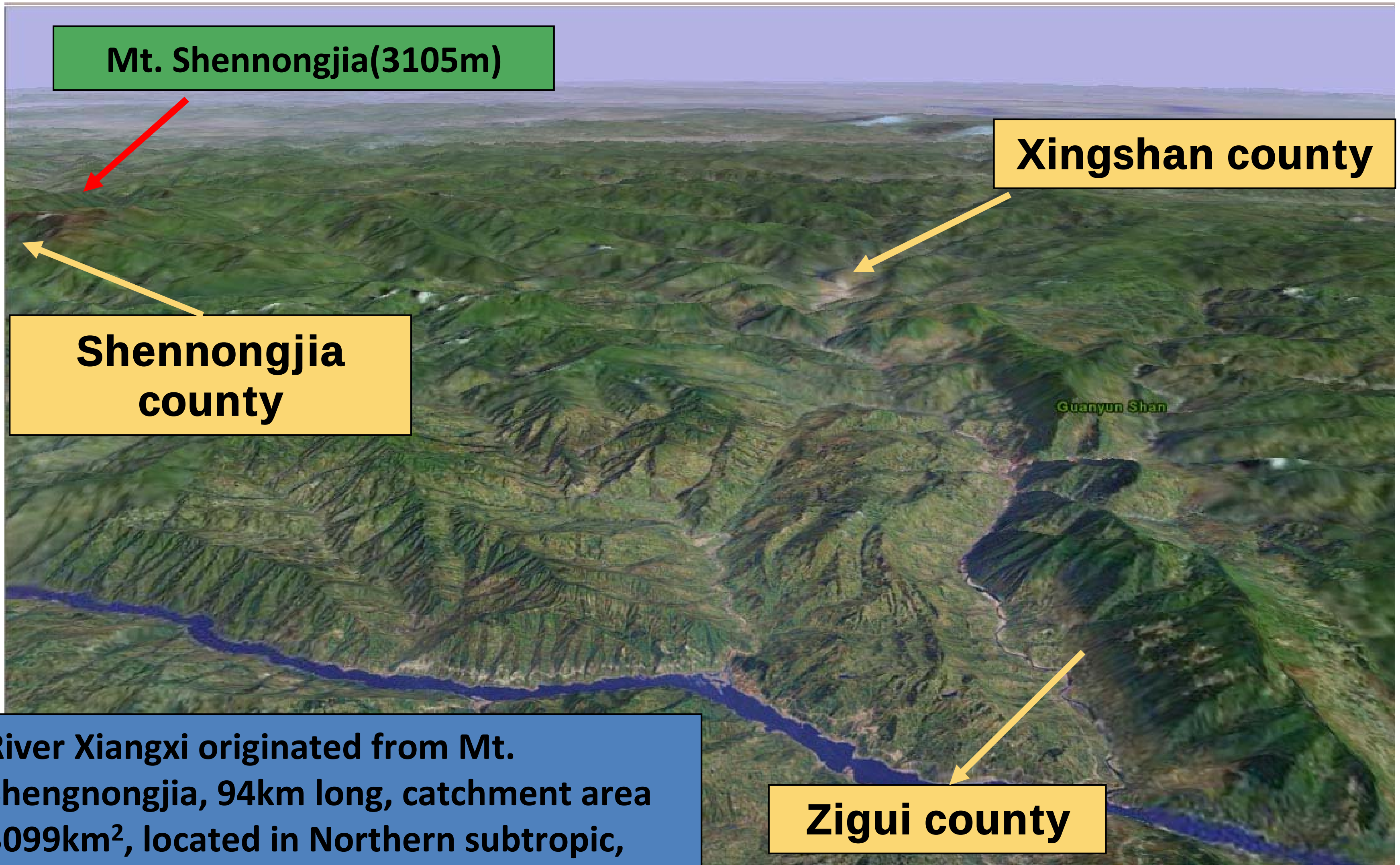
1. Study Area: Yangtze Valley, the Three Gorges Reservoir (TGR) and River Xiangxi



Xiangxi River is the largest tributary in Hubei part of TGR, most close to the Dam.

Source: Cai, CIMCGWM, 2007

1. Study Area: Location of River Xiangxi



River Xiangxi originated from Mt. Shengnongjia, 94km long, catchment area 3099km², located in Northern subtropic, Southeast China

Source: Cai, CIMCGWM, 2007

1. Study Area: River Xiangxi

- Annual precipitation observed from 1961 to 2004 is 1100mm and ranges from 670mm to 1700mm with considerable spatial and temporal variations.
- The distribution is characterized by a dry winter and a summer monsoon from May to September.
- Annual average temperature from 1961 to 2004 is 15.6°C and ranges from 12°C and 20°C.
- The slopes are covered by forests. The main agricultural crops are rice and wheat in the valleys. Terraced fields are often used for corn and potatoes and a considerable area of tea.
- The soils are mainly limestone soils in the upper regions and brown and yellow- brown soils in the lowlands.

1. Study Area: High Erosion and Nutrient Transport in River Xiangxi

Source: Vortrag CIMCGWM, 2007

2. Hydrological Modeling Based SWAT：General Description of SWAT

SWAT (Soil and Water Assessment Tool) is a continuation of nearly 30 years of modeling efforts conducted by the USDA Agricultural Research Service .

- A semi-distributed hydrologic model
- Water fluxes, Nutrients,Yield, Pesticides
- Continuous Time
  - Daily Time Step
  - One day to Hundreds of Years
- Unlimited numbers of Subwatersheds
- Comprehensive-Processes Interaction
- Simulation Management
- Programmed in FORTRAN
- User interfaces for GRASS, ArcView, ArcGIS

2. Hydrological Modeling Based SWAT: Model Setup and Evaluation

Method:

Potential eva-potranspiration: Hargreaves function

Surface runoff : SCS CN method

Routing processes: Muskingum method

Time Scale: Monthly

Evaluation: For discharge

Mean and standard deviation of discharge (SD),

Coefficient of determination (R^2)

Nash-Sutcliffe efficiency (E_{ns})

2. Hydrological Modeling Based SWAT: Sensitivity, Auto-calibration, Uncertainty in SWAT2005

The LH-OAT sensitivity analysis

Latin-hypercube simulations

One-factor-At-a-Time sampling

Parasol (Parameter Solution method) : optimization and uncertainty analysis in a single run

Optimization method:

The Shuffled complex evolution algorithm

Objective function: SSQ, SSQR

Multi-objective optimization

Parameter change options:

A lumped way, a distributed way by

Addition of an absolute change, multiplication of a relative change

Uncertainty analysis method (Threshold value)

X^2 method

Bayesian method

2. Hydrological Modeling Based SWAT: Data Sources

DATA	SOURCE
DEM	1:250,000 from China Fundamental Geographic Information Center
SOIL	1:1,000,000 from Environment and Ecology Scientific Data Center of western China, National Natural Science Foundation of China
LAND USE	1:100,000 from Hubei Land Management Bureau, and Inner mongolia
METEOROLIGCAL DATA	Daily observation station from Hubei and Inner mongolia Meteorological and Bureau(**OBS**) ,Monthly girded observation data of CRU3.0(1960-1990)(0.5ºx0.5º) from Climate Research Unit, University of East Anglia,UK(**CRU**)
DISCHARGE DATA	1970-1986 monthly and daily discharge from Hubei Hydrological Information Center for River Xiangxi, and 1963-74 monthly and Daily discharge from Hydrological Annual Report for Huangfuchuan basin

2. Hydrological Modeling Based SWAT: Soil Attribute

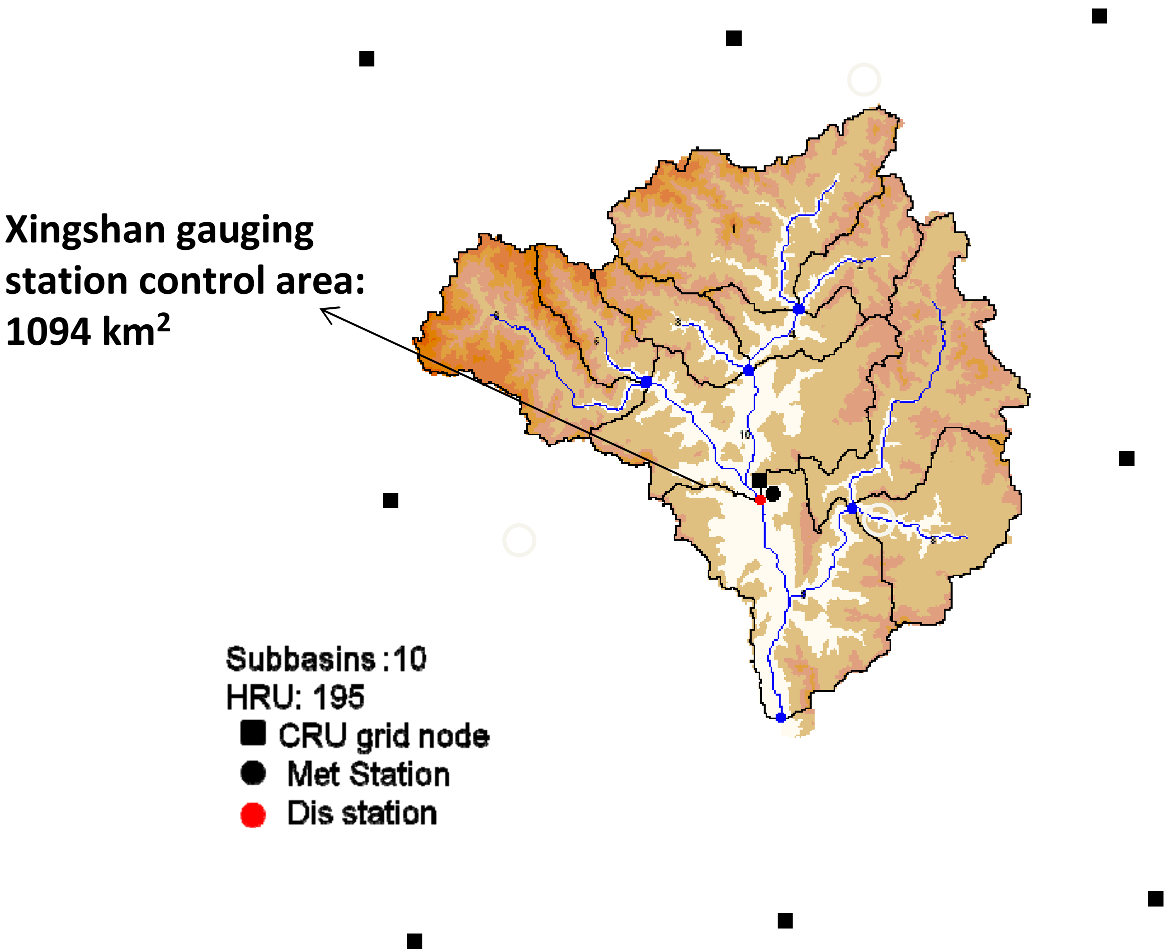
Attribute Data Set: “*Soil Species of China (six volumes)*” and other sources

Total Information includes 7,300 soil profiles collected from all over China

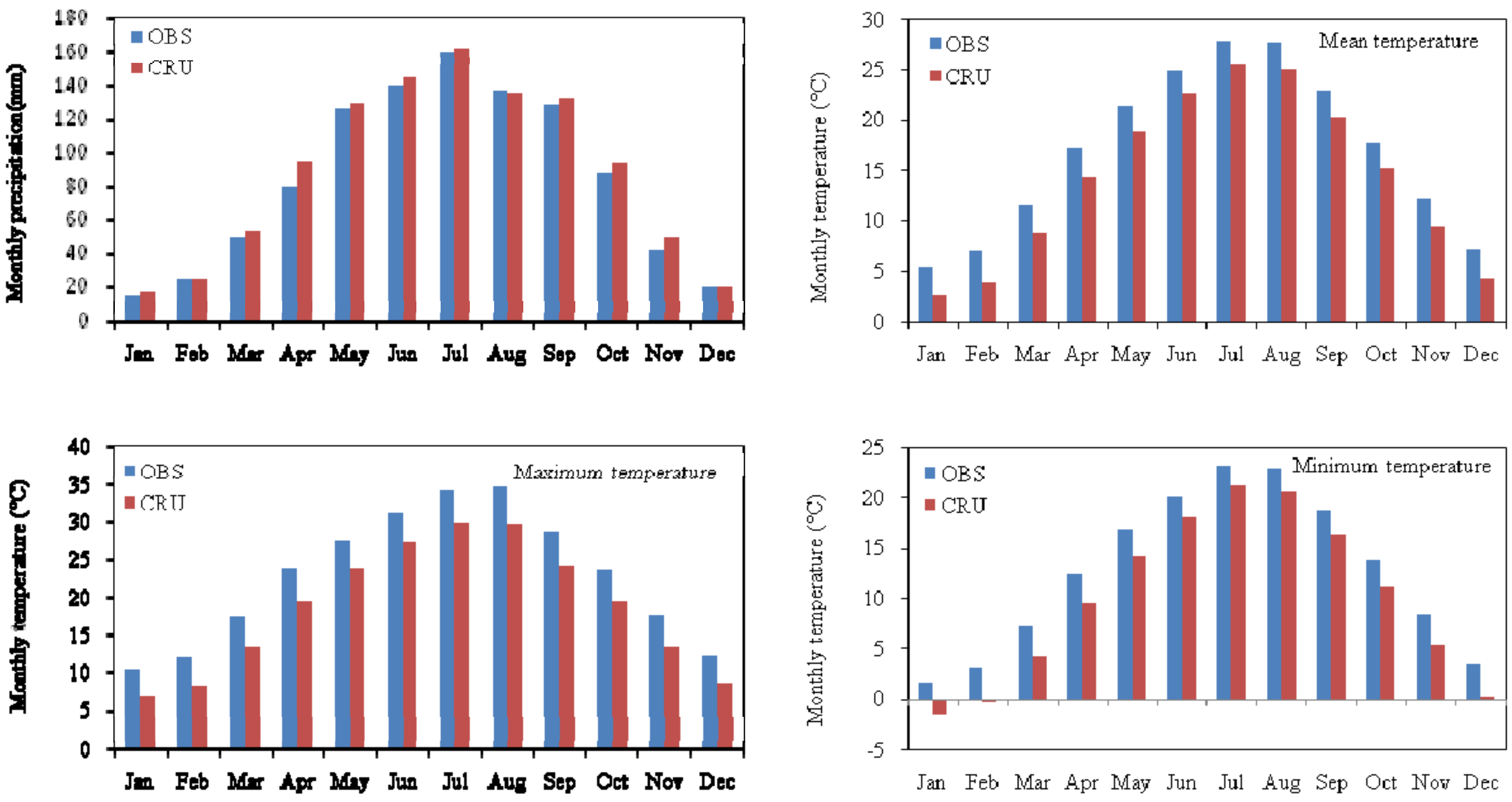
Some attribute data of one soil profile within GSCC

Order	Great group	Sub group	Family	Species	Horizon	Thick-ness (cm)	Sand (%)	Silt (%)	Clay (%)	Buck density
Anthro-sols	Paddy soils	Redoxing paddy soil	马肝泥田	马肝土	Aa	15	29.38	46.12	24.5	1.25
					Ap	10	32.18	50.32	17.5	1.43
					P	25	25.79	42.01	32.2	1.54
					W1	24	23.44	37.97	37.9	1.57
					W2	26	14.92	40.98	44.1	1.48

2. Hydrological Modeling Based SWAT: CRU Grid Node, Meteorological and Discharge Station in River Xiangxi

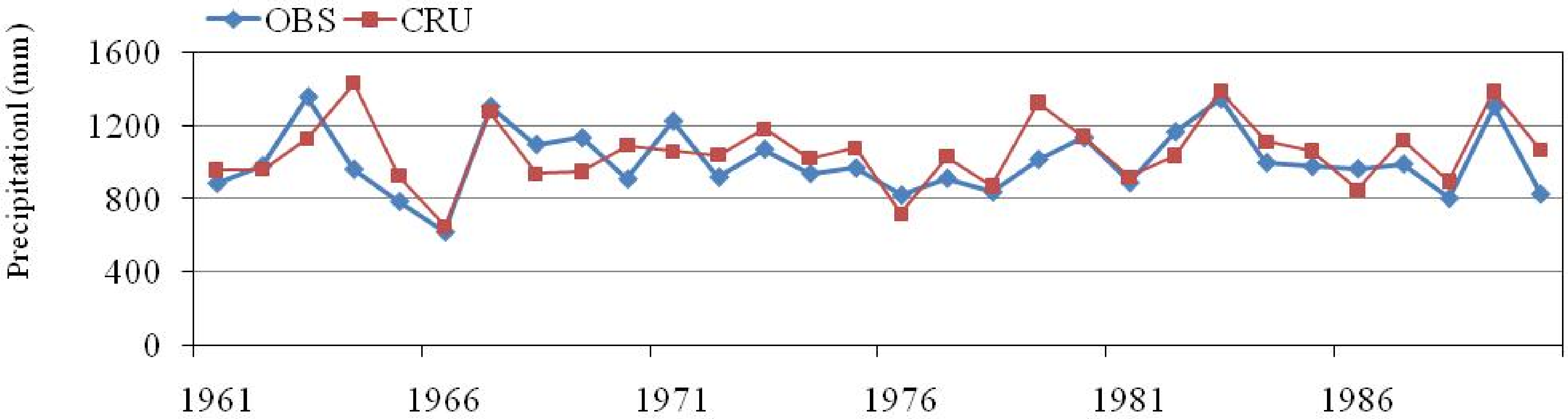


2. Hydrological Modeling Based SWAT: Precipitation and Temperature (OBS and CRU , 1960-90) in River Xiangxi

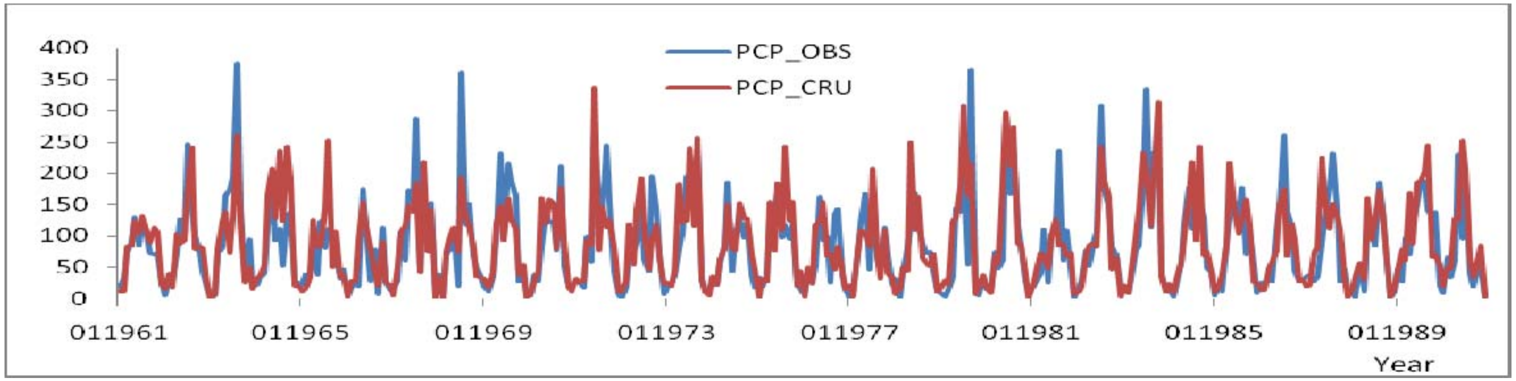


Average monthly precipitation, and mean, maximum and minimum temperature variation for OBS and CRU

2. Hydrological Modeling Based SWAT: Precipitation (OBS and CRU , 1960-90) in River Xiangxi



Annual precipitation for OBS and CRU3.0 for 1961-90



Monthly precipitation for OBS and CRU3.0 for 1961-90

2. Hydrological Modeling Based SWAT: Statistics of Precipitation (OBS and CRU , 1960-90) in River Xiangxi

Statistics of OBS and CRU (average over all three CRU grids) precipitation for period 1961-1990

Monthly data	OBS	CRU
Average monthly total (mm)	83.6	87.7
Standard deviation (mm)	70.1	69.9
Average winter (DJF;mm)	57.2	59.8
Average spring (MAM;mm)	253.6	277.0
Average summer (JJA;mm)	435.0	440.5
Average autumn (SON;mm)	257.2	274.9
Daily data	**OBS**	**CRU**
Rain days	136	117
Wet day amount (mm)	7.38	9.18
Wet day std deviation (mm)	11.75	18.71
Median (mm)	2.7	2.3
Maximum daily value (mm)	160.8	225.0

More heavy rainfall

2. Hydrological Modeling Based SWAT: Sensitivity Results by SWAT2005:OBS and CRU in River Xiangxi

Sensitivity results for pre-define parameters by SWAT2005 based on OBS and CRU dataset
(parameters with no appearance of sensitivity give rank 28)

Name	Processes	OBS	CRU
CN2	Runoff	1	1
CANMX	Runoff	2	2
SOL_AWC	Soil	3	3
SOL_Z	Soil	4	4
ESCO	Evaporation	5	5
BIOMIX	Soil	6	6
SOL_K	Soil	7	8
ALPHA_BF	Groundwater	8	7
CH_K2	Channel	9	14
SURLAG	Runoff	10	16
SMTMP	Snow	11	10
EPCO	Evaporation	12	15
SFTMP	Snow	13	9

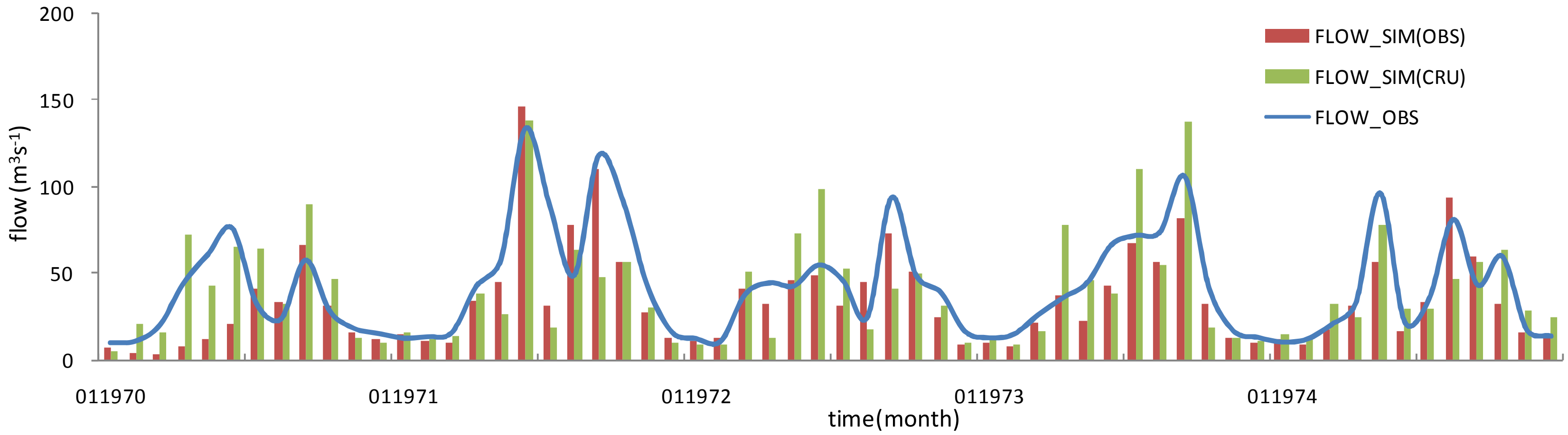
Name	Processes	OBS	CRU
SMFMX	Snow	14	11
TIMP	Snow	15	13
CH_N	Channel	16	18
SMFMN	Snow	17	17
SLOPE	Geomorphology	18	19
SOL_ALB	Evaporation	19	12
GWQMN	Soil	28	28
GW_REVAP	Groundwater	28	28
REVAPMN	Groundwater	28	28
SLSUBBSN	Geomorphology	28	28
TLAPS	Geomorphology	28	28
GW_DELAY	Groundwater	28	28
RCHRG_DP	Groundwater	28	28
BLAI	Crop	28	28

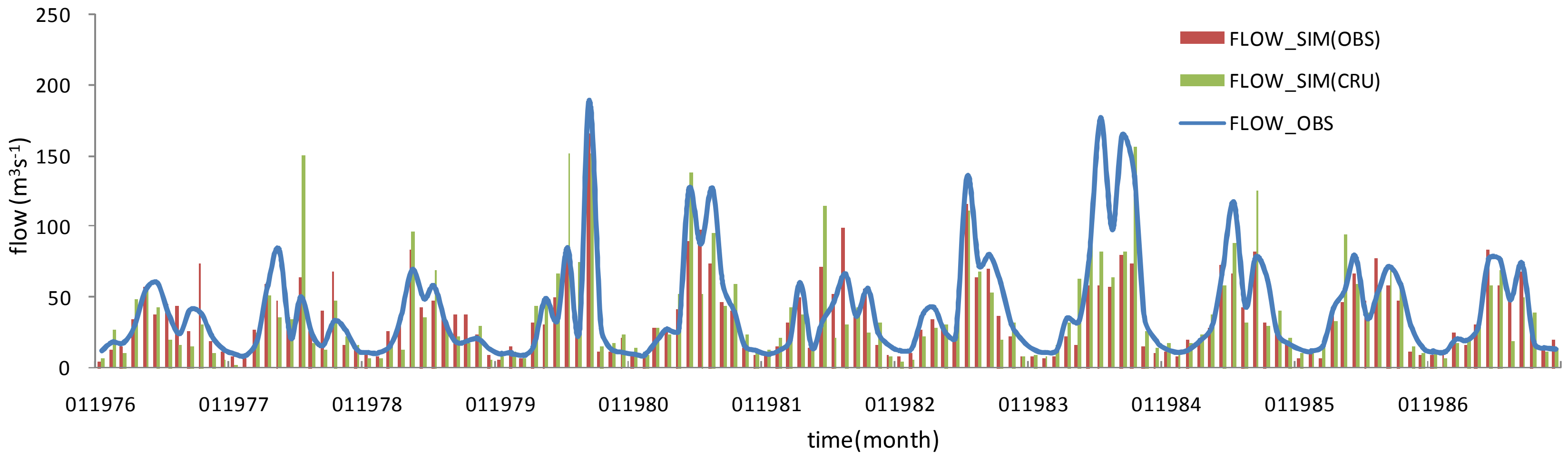
2. Hydrological Modeling Based SWAT: Autocalibrated Parameters (OBS and CRU, monthly) in River Xiangxi

Autocalibrated parameters selected for discharge simulation of the SWAT2005 model based on OBS and CRU

Parameter	Definition	Range	OBS	CRU
CANMX	Maximum canopy storage	0-10	2.23	2.59
ESCO	Soil evaporation compensation factor	0-1	0.33	0.53
CH_K2	Effective hydraulic conductivity in the main channel	0-150	146.3	146.9
SURLAG	Surface runoff lag coefficient	0-10	3.80	8.22
CN2	SCS runoff curve number for moisture condition II	35-98	82.3	71.8
BIOMIX	Biological mixing efficiency	0-1	0.74	0.83
ALPHA_BF	Baseflow alpha factor (days)	0-1	0.03	0.03

2. Hydrological Modeling Based SWAT: Observed and Simulated Discharge (Monthly) in River Xiangxi





Monthly discharge at Xingshan gauging station for calibration and validation period (upper: calibration, bottom: validation, the blue line is observed discharge, and red box is discharge simulated by OBS climatic datasets, and the green box is discharge simulated by CRU climatic datasets)

2. Hydrological Modeling Based SWAT: Observed and Simulated Discharge Statistic (Monthly) in River Xiangxi

Observed and autocalibration tool parameter adjustment discharge simulation statistics based on OBS and CRU (m^3 s^{-1} $month^{-1}$)

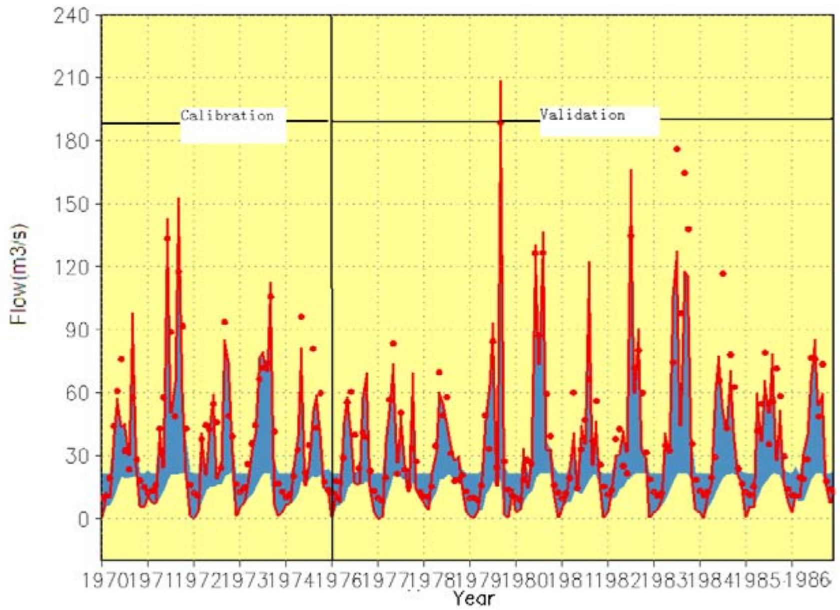
Period	Observed		Simulated by OBS				Simulated by CRU			
	Mean	SD	Mean	SD	Nash	R^2	Mean	SD	Nash	R^2
Calibration (1970-1974a)	42.0	30.0	36.7	34.4	0.50	0.7	31.2	22.4	0.45	0.5
Validation (1976-1986a)	39.8	35.5	36.2	36.5	0.64	0.8	30.5	26.1	0.55	0.6

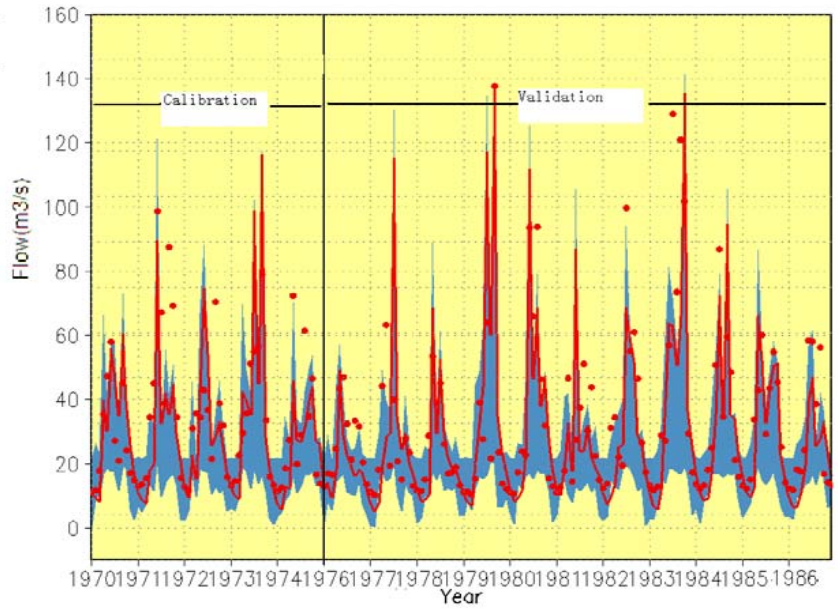
2. Hydrological Modeling Based SWAT: Simulated Water Balance (OBS and CRU) in River Xiangxi

Water balance for 1961-1990a simulated based on OBS and CRU (mm)

Average Annual (mm)	OBS	CRU_3.0
Precipitation	1003	1052
Surface Runoff	100	88
Lateral Soil Flow	380	420
Groundwater flow	1	4
ET	522	541
PET	1269	1063

2. Hydrological Modeling Based SWAT: Uncertainty of Discharge Simulation (OBS and CRU) in River Xiangxi





Right: Uncertainty based on OBS, Left: Uncertainty Based on CRU

3. Climate Change Impact: Climate Scenarios

1.Baseline:

CRU detrended climate data 1961-90 (CRU_DTF)

2. Scenarios:

1-6 °C increase in global mean temperature for HadCM3

2 °C increase across all seven GCMs

UKMO HadCM3 & HadGEM1, CCCMA, CSIRO, IPSL, MPI and NCAR

All four SRES (A1B, B1, B2, A2) scenarios on HadCM3 (2010-99)

SRES A1B across all seven GCMs (2010-99)

3. Climate Change Impact: Change in Temperature in River Xiangxi

Anomalies of annual temperature under 1-6 DG and 2DG global warming based CRU_DTF(1961-90) (℃)

Scenarios	UKMO_HADCM3_1DG	UKMO_HADCM3_2DG	UKMO_HADCM3_3DG	UKMO_HADCM3_4DG	UKMO_HADCM3_5DG	UKMO_HADCM3_6DG	
anomalies of annual temperature(℃)	1.42	2.36	4.25	5.67	7.09	8.51	
Scenarios	UKMO_GEM_2DG	NCAR_CCSM30_2DG	MPI_ECHAM5_2DG	IPSL_CM4_2DG	CSIRO_MK30_2DG	CCCMA_CGCM31_2DG	AVE_2DG
anomalies of annual temperature(℃)	2.18	2.32	2.56	2.83	2.25	2.60	2.46

3. Climate Change Impact: Change in Temperature in River Xiangxi

Anomalies of annual temperature under SRES A1B scenarios based CRU_DTF(1961-90) (℃)

Scenarios	UKMO_HADCM3_A1B	UKMO_GEM_A1B	NCAR_CCSM30_A1B	MPI_ECHAM5_A1B	IPSL_CM4_A1B	CSIRO_MK30_A1B	CCCMA_CGCM31_A1B	AVE_A1B
2010 - 39a	1.70	1.07	1.00	1.64	1.62	0.93	1.41	1.34
2040 - 69a	3.41	2.14	2.00	3.39	3.35	1.87	2.90	2.72
2070 - 99a	4.85	3.06	2.85	4.94	4.91	2.66	4.16	3.92

Anomalies of annual temperature under SRES A1B, B1, B2 and A2 scenarios based CRU_DTF(1961-90) (℃)

Scenarios	UKMO_HADCM3_A1B	UKMO_HADCM3_B1	UKMO_HADCM3_B2	UKMO_HADCM3_A2
2010 - 39a	1.70	1.54	1.73	1.57
2040 - 69a	3.41	2.56	2.96	3.23
2070 - 99a	4.85	3.40	4.20	5.55

3. Climate Change Impact: Seasonal Temperature and Precipitation in River Xiangxi

The scenarios trend in temperature and precipitation based CRU_DTF(1961-90)

	Anomalies of Mean Temperature(℃					Percentage Change of Precipitation(%)				
Scenarios	MAM	JJA	SON	DJF	Average	MAM	JJA	SON	DJF	Annual
CRU_DTF	14.49	24.31	14.24	3.58	14.20	65.92	288.8	437.26	261.33	1053.3
UKMO_HADCM3_1DG	1.7	1.3	1.1	1.5	1.4	7.8	4.5	7.0	13.6	8.2
UKMO_HADCM3_2DG	2.8	2.9	1.8	2.0	2.4	9.3	6.1	24.6	24.4	16.1
UKMO_HADCM3_3DG	5.2	4.3	3.2	4.3	4.3	18.8	11.8	25.4	38.7	23.7
UKMO_HADCM3_4DG	6.9	5.7	4.3	5.7	5.7	26.1	11.3	34.9	56.7	32.3
UKMO_HADCM3_5DG	8.6	7.2	5.3	7.2	7.1	29.4	13.6	45.3	78.7	41.8
UKMO_HADCM3_6DG	10.3	8.7	6.4	8.6	8.5	36.7	16.0	52.2	89.3	48.6
UKMO_GEM_2DG	2.6	2.3	1.8	2.0	2.2	9.1	-13.7	2.5	11.1	2.2
NCAR_CCSM30_2DG	2.6	2.3	2.2	2.1	2.3	11.6	13.4	3.8	3.5	8.1
MPI_ECHAM5_2DG	2.5	2.3	2.9	2.6	2.6	11.3	-3.6	-8.6	7.7	1.7
IPSL_CM4_2DG	3.0	2.7	2.9	2.7	2.8	14.3	2.3	4.6	-16.1	1.3
CSIRO_MK30_2DG	2.6	1.9	2.2	2.4	2.2	4.9	5.5	-13.8	19.4	4.0
CCCMA_CGCM31_2DG	2.3	2.0	3.3	2.8	2.6	18.1	12.7	3.8	9.9	11.1
UKMO_HADCM3_B1	1.7	2.9	3.3	1.9	2.4	4.6	5.3	21.3	33.7	16.2
UKMO_HADCM3_B2	2.2	3.5	3.7	2.2	2.9	6.1	6.2	24.3	41.9	19.6
UKMO_HADCM3_A2	2.6	4.0	4.3	2.6	3.4	8.1	6.7	25.9	46.6	21.8

3. Climate Change Impact: Water Balance in River Xiangxi

Water balance change based on UKMO_HADCM3 output for temperature increased 1-6℃(%)

Water Balance Component	UKMO_HADCM3_1DG	UKMO_HADCM3_2DG	UKMO_HADCM3_3DG	UKMO_HADCM3_4DG	UKMO_HADCM3_5DG	UKMO_HADCM3_6DG
Precipitation	5.6	11.0	11.8	22.2	27.6	32.9
Surface runoff	22.5	41.3	43.8	116.1	138.7	155.9
Lateral soil Flow	6.8	13.0	14.2	23.6	29.2	35.3
Percolation	13.4	34.4	18.7	76.9	101.5	145.4
ET	2.9	6.3	6.6	11.1	14.5	17.8
PET	4.9	6.4	14.4	19.3	24.2	29.2

Water balance change based on 6 GCMs models output for temperature increased 2℃ (%)

Water Balance Component	UKMO_GEM_2DG	NCAR_CCSM30_2DG	MPI_ECHAM5_2DG	IPSL_CM4_2DG	CSIRO_MK30_2DG	CCCMA_CGCM31_2DG
Precipitation	-1.6	-1.6	-0.1	6.3	1.6	11.5
Surface runoff	-0.2	79.1	14.2	33.8	5.0	40.0
Lateral soil Flow	-0.6	9.9	0.4	6.6	2.4	12.1
Percolation	-9.0	20.7	-12.8	6.2	-22.5	11.0
ET	-2.5	4.8	-1.8	3.2	0.9	8.1
PET	7.4	5.9	8.3	9.3	8.9	8.3

3. Climate Change Impact: Water Balance in River Xiangxi

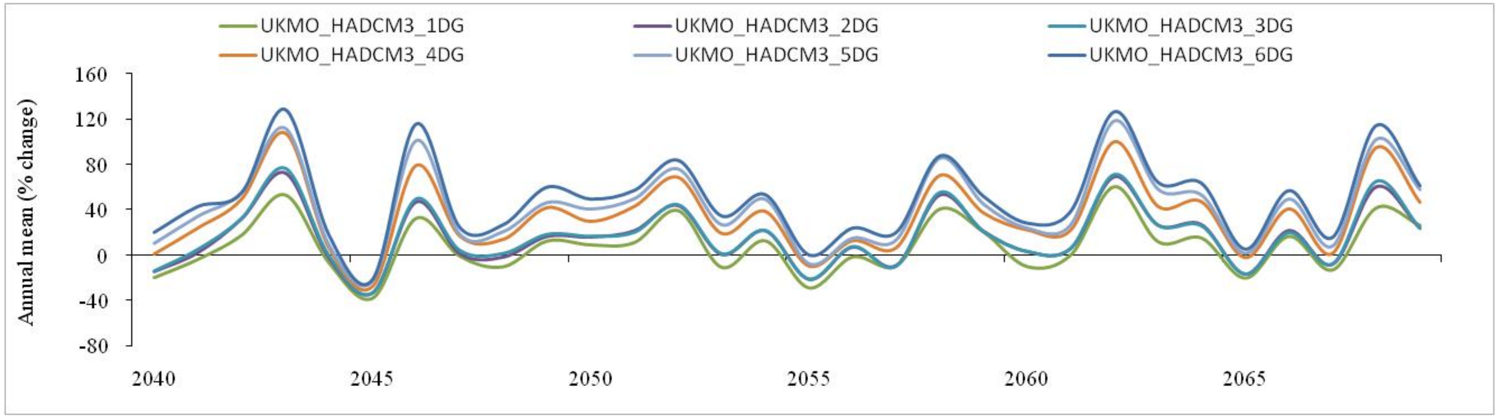
Water balance change based on 7 GCMs models output for SRES A1B (%)

Water Balance Component	UKMO_HADCM3_A1B	UKMO_GEM_A1B	NCAR_CCSM30_A1B	MPI_ECHAM5_A1B	IPSL_CM4_A1B	CSIRO_MK30_A1B	CCCMA_CGCM31_A1B
Precipitation	-1.3	12.5	9.1	0.0	7.4	1.4	12.3
Surface runoff	-6.3	16.7	40.9	9.5	20.9	0.2	21.8
Lateral soil Flow	-1.0	13.5	8.6	-0.1	7.5	1.8	13.1
Percolation	22.0	51.3	54.0	17.6	31.9	28.2	59.0
ET	-1.3	10.8	5.8	-1.1	5.6	0.9	10.3
PET	6.6	10.8	4.6	10.2	10.6	6.8	8.5

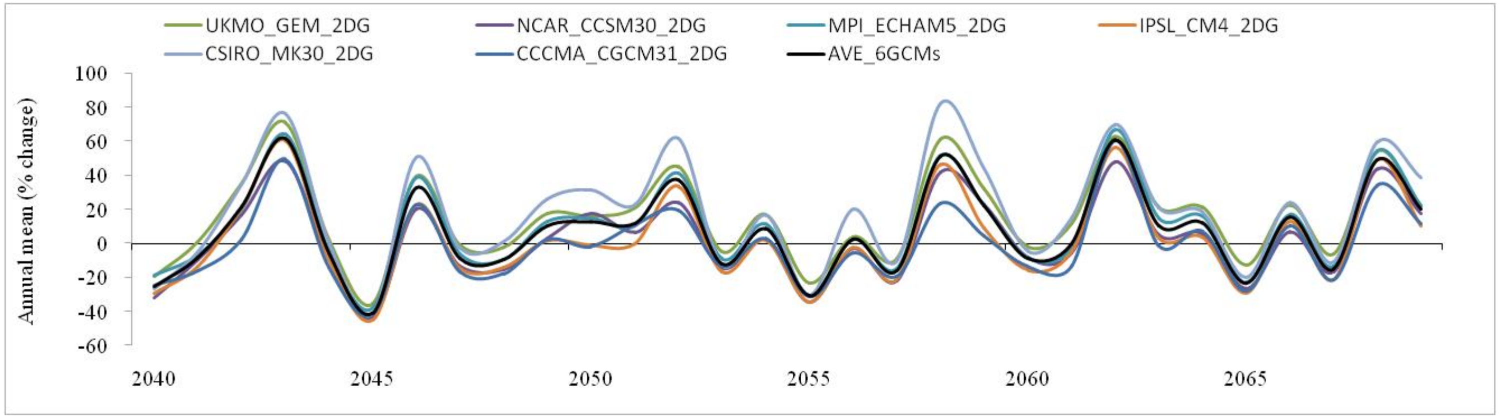
Water balance change based on UKMO_HADCM3 output for SRES B1, B2, A2, A1B(%)

Water Balance Component	UKMO_HADCM3_A1B	UKMO_HADCM3_B1	UKMO_HADCM3_B2	UKMO_HADCM3_A2
Precipitation	-1.3	9.5	11.2	12.9
Surface runoff	-6.3	10.9	5.4	17.8
Lateral soil Flow	-1.0	10.6	12.0	13.7
Percolation	22.0	47.8	46.9	44.7
ET	-1.3	8.0	10.7	11.4
PET	6.6	8.1	9.6	11.3

3. Climate Change Impact: Annual Mean Discharge in River Xiangxi

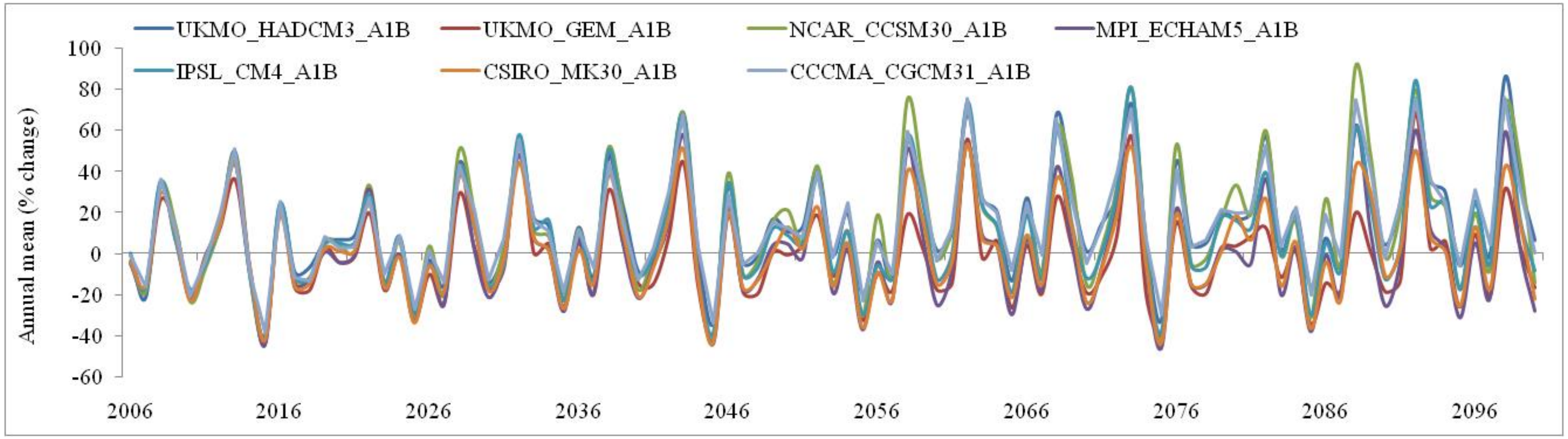


Changes in annual mean discharge simulated for 1-6DG global warming scenarios by UKMO_HADCM3

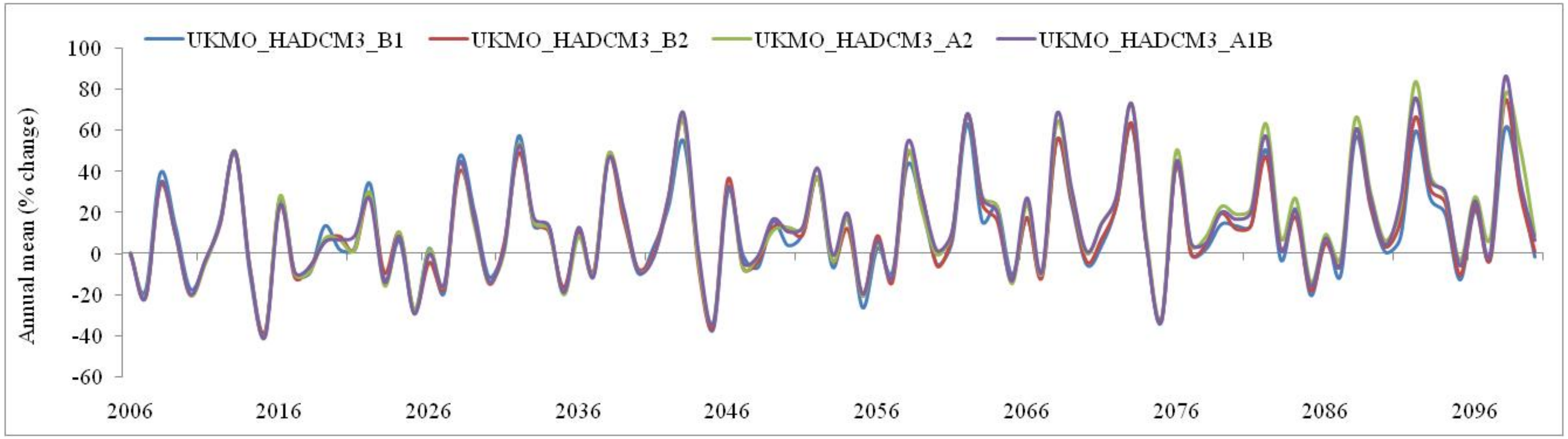


Changes in annual mean discharge simulated for 2DG global warming scenarios by 6 GCMs

3. Climate Change Impact: Annual Mean Discharge in River Xiangxi

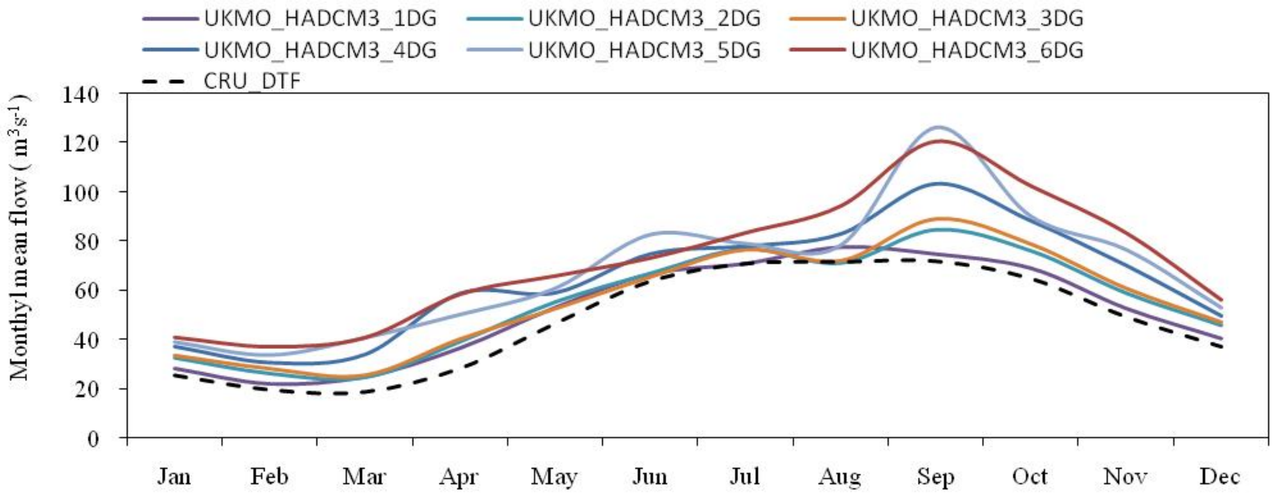


Annual mean discharge changes simulated for SRES A1B by 7GCMs

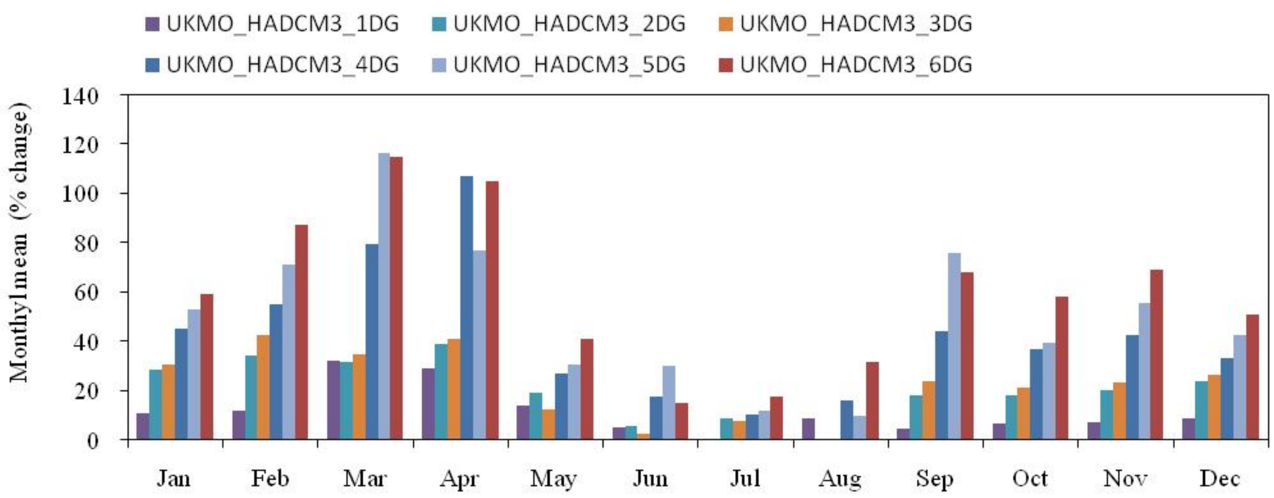


Annual mean discharge changes simulated for SRES B1, B2, A2, A1B by UKMO_HADCM3

3. Climate Change Impact: Monthly Mean Discharge in River Xiangxi

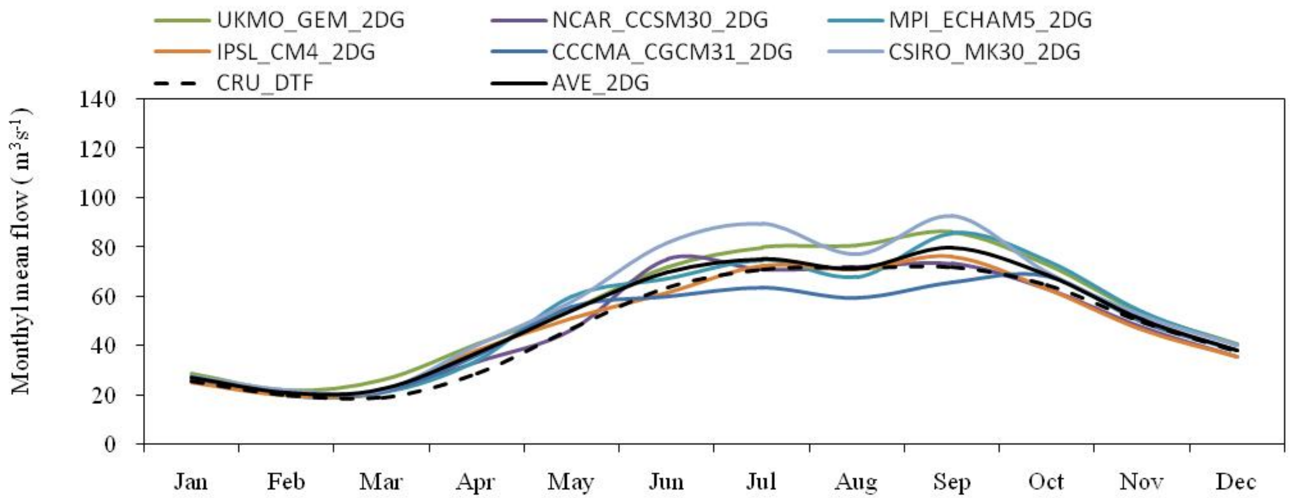


Monthly mean discharge simulated for1-6DG global warming scenarios

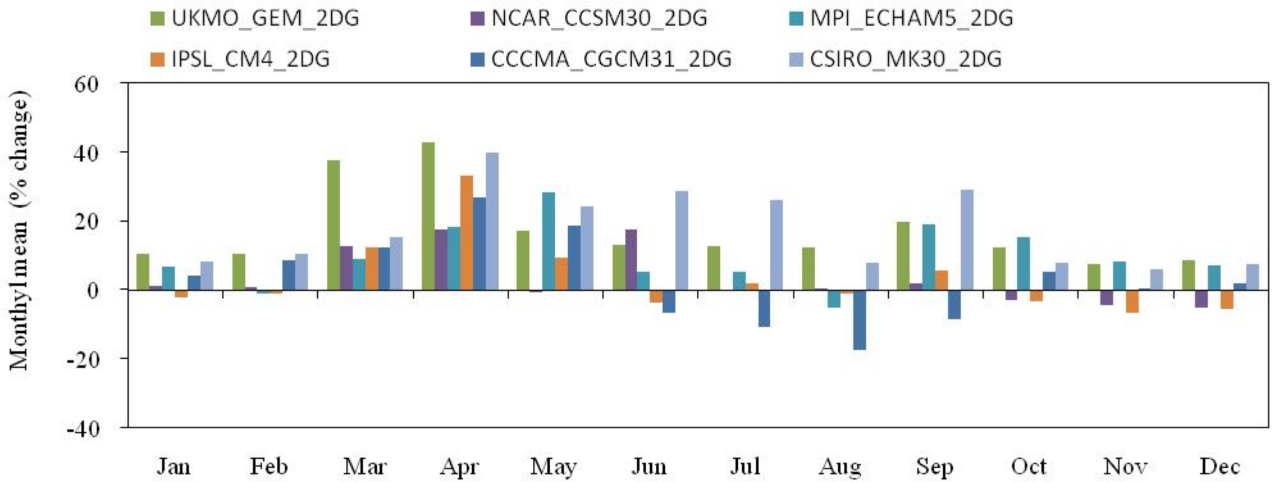


Changes in monthly mean discharge simulated for 1-6DG global warming scenarios

3. Climate Change Impact: Monthly Mean Discharge in River Xiangxi

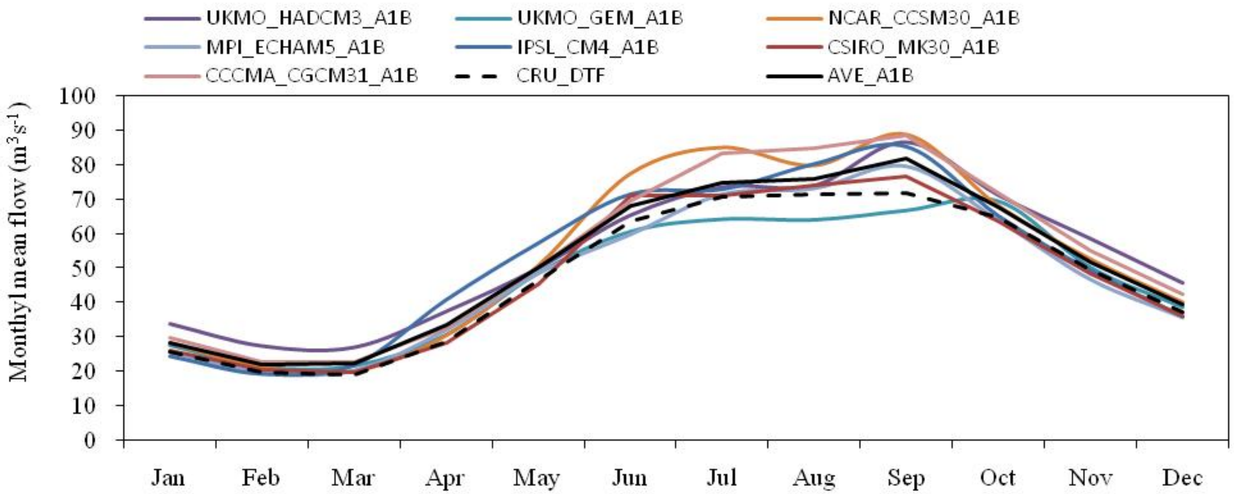


Monthly mean discharge simulated for2DG global warming scenarios by 6 GCMs

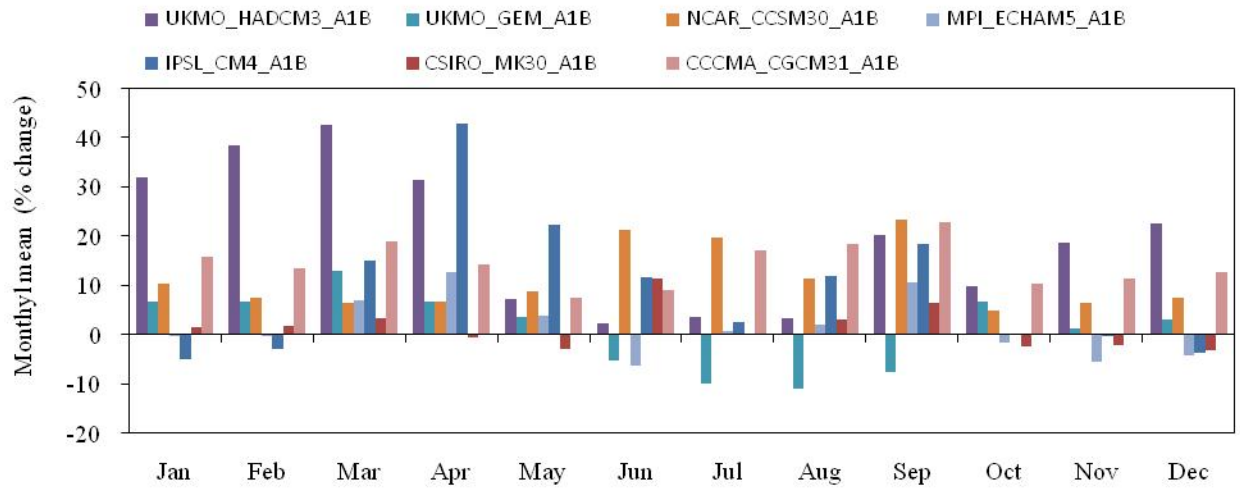


Changes in monthly mean discharge simulated for 2DG global warming scenarios by 6 GCMs

3. Climate Change Impact: Monthly Mean Discharge in River Xiangxi

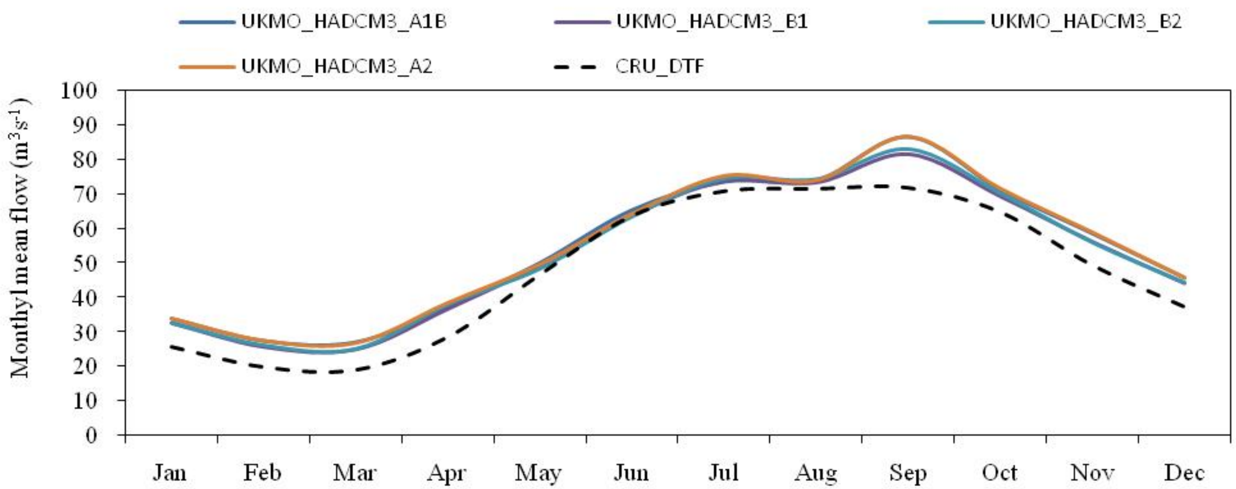


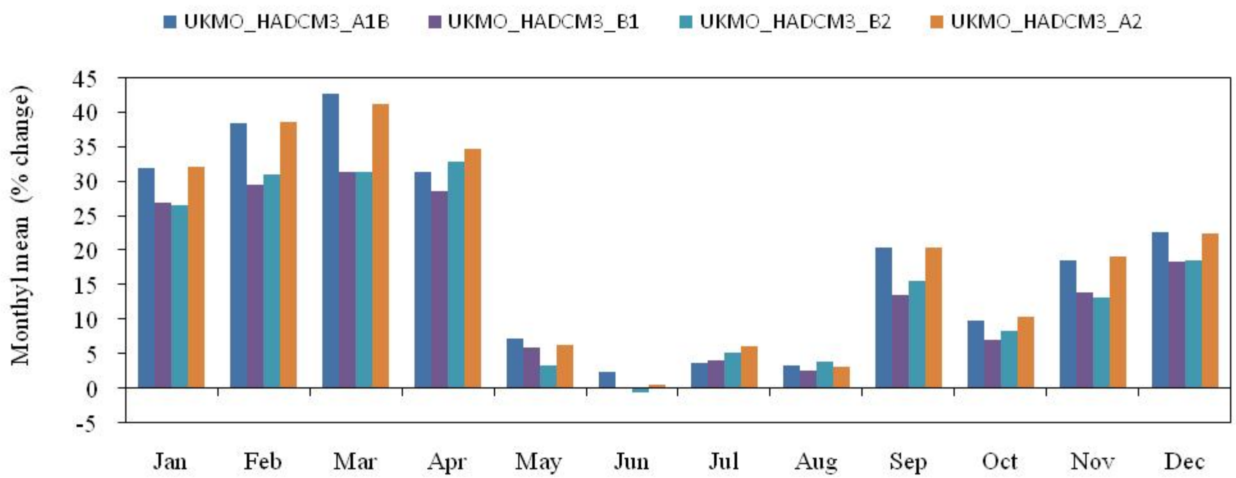
Monthly mean discharge simulated for SRES-A1B by 7 GCMs for 2010-99



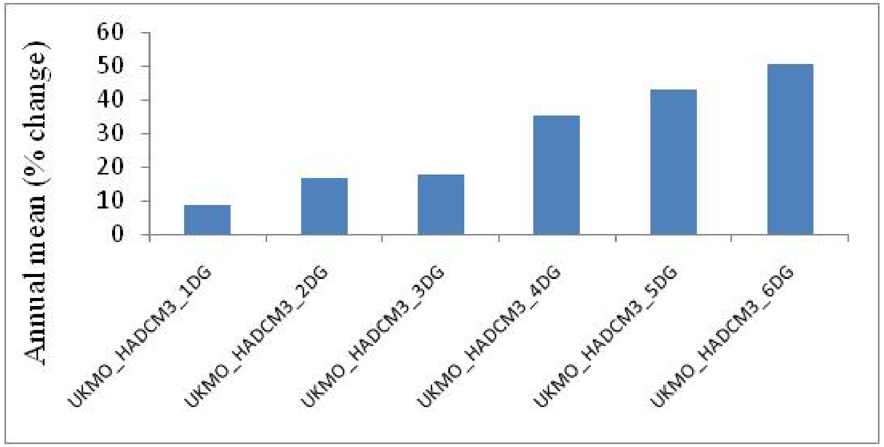
Changes in monthly mean discharge simulated forSRES-A1B by 6 GCMs for 2010-99

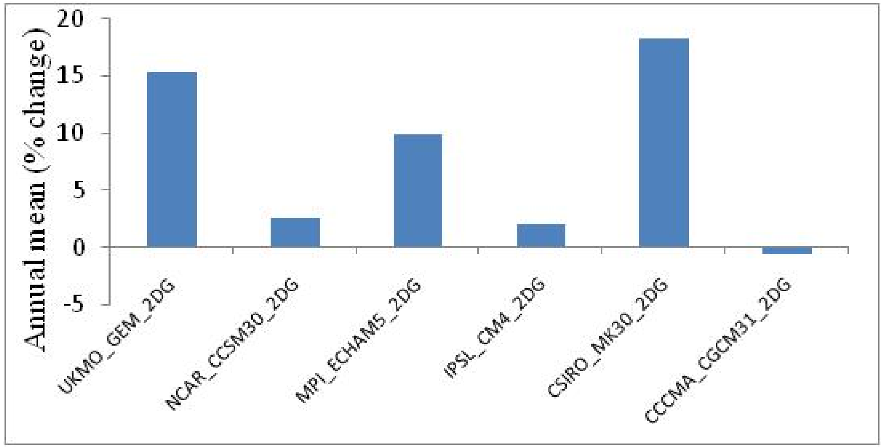
3. Climate Change Impact: Monthly Mean Discharge in River Xiangxi

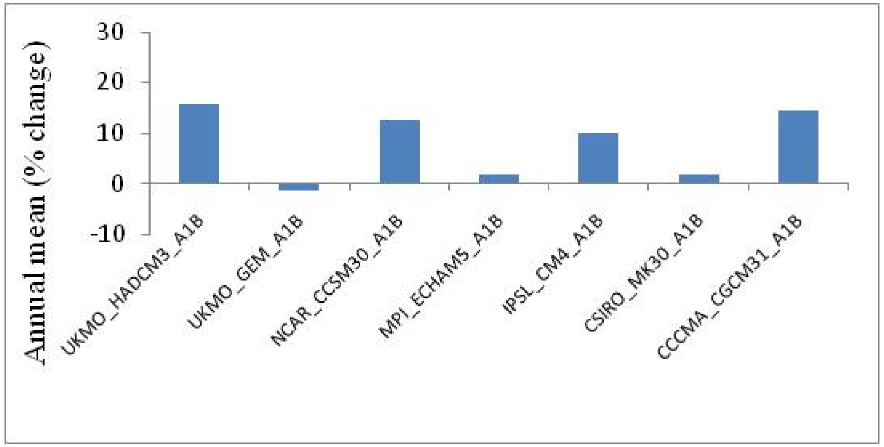


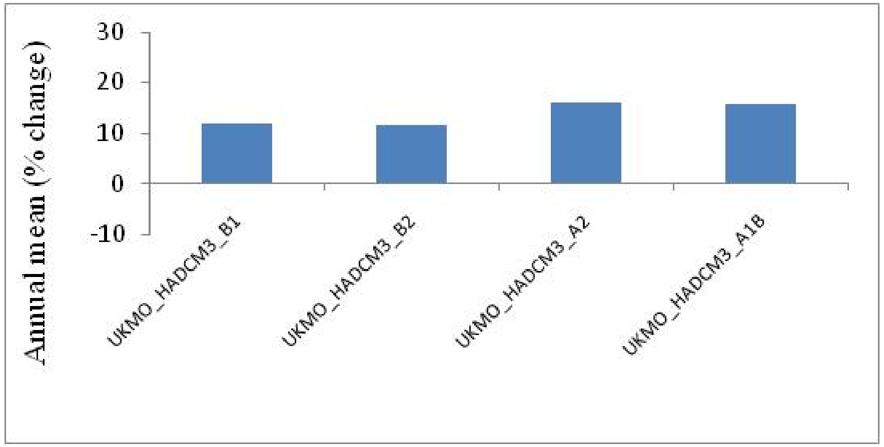


3. Climate Change Impact: Changes in Annual Mean Discharge in River Xiangxi









4. Summary and Outlook

■After model calibration, CRU data shows good for discharge simulation in the study area based on SWAT2005 . CRU data maybe very useful for data-sparse area in hydrological modelling.

■Climate change have direct impact on water cycle: surface runoff, lateral runoff, percolation, and ET. For most scenarios, surface runoff and percolation are most sensitive to climate change.

■Climate change impacts on water resources strongly depend on the applied climate scenario. It is very important to quantify the uncertainty of climate change impact on water resource

■Hydrologic impact of climate change using multi-model ensembles of future climate and hydrological model ensembles


Thanks for your attention!