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A modeling study of catchment discharge to Poyang Lake under future climate in China

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ABSTRACT

Poyang Lake, the largest freshwater lake in China, is an important water resource and iconic ecosystem in a region that has been subjected to extreme droughts and floods in recent decades. The lake's water level is heavily influenced by the watershed inflows and also by the Yangtze River from the north of the lake basin. Assessing the impact of future climate change on the watershed inflows and the subsequent influence on changes in the lake water level is important for developing effective management strategies for local water resources and for mitigation of future droughts and floods. In this study, the large-scale, distributed hydrological model, WATLAC, was applied to the Poyang lake watershed to study the possible impacts of future climate change on both inflow generation and changes in lake water level. The Global Circulation Model ECHAM5 was used to predict future climate conditions for the watershed. Simulations of WATLAC show that annual catchment inflow will increase by 2.9% and 6.5% for A1B and B1 scenarios, respectively, and will decrease by 5.2% for A2 scenario for 2011–2050 compared to that for 1961–2000. Further analyses demonstrate that changes in monthly distribution of catchment inflow will result in an increase of lake water level of 0.10–1.34 m from February to July and a decrease of 0.32–1.31 m from September to February under the three climate change scenarios. It is concluded that climate change impacts on Poyang Lake are expected to be manifested with more extreme droughts and floods in the future.

1. Introduction

Poyang Lake is the largest freshwater lake in China, and a critical area for migratory waterfowl (Kanai et al., 2002). As an important water reservoir and iconic ecosystem in southeastern China, Poyang Lake and its surrounding catchments have suffered frequent droughts and floods, particularly in recent decades. From 1950 to 2005, there have been 46 flooding events in the catchment, including the most severe ones in 1954, 1983, 1995, 1998 and 1999 (Wang et al., 2008). The estimated economic loss due to the 1998 flood was about ¥38 billion. Between the floods, droughts often emerged and persisted. Statistical studies have indicated that severe droughts occurred 22% of the time during 1953–2003 (Min, 2007). The recent severe winter drought in 2006–07 brought the lake water storage down to less than 1% of the lake capacity.

These severe droughts and floods have raised concerns for the lake ecology and local water resources management. Studies addressing such concerns have indicated that droughts and floods in the catchment were primarily caused by climate anomalies, although human activities such as land-use change and modifications to river systems (including the Yangtze River) also have contributed to the impacts of droughts and floods (Liu and Wu, 1999; Min, 2002; Guo et al., 2008a). Because Poyang Lake is connected to the Yangtze River, the lake water level is affected by water exchange with the Yangtze River, in addition to the runoff from the lake catchments. Recent studies suggested that the catchment runoff plays a primary role in influencing the lake water level and the exchange with the Yangtze River plays a complementary blocking role (Hu et al., 2007). During 1960–2003, all the severe flooding were attributed to the strong Poyang Lake catchment effect (Hu et al., 2007). Inflows from the lake catchment to the lake increased substantially concurring with the increasing warm season rainfall in Poyang Lake and surrounding regions south of the Yangtze River, a relationship underlining a strong climate effect on the lake level fluctuation (Hu and Feng, 2001).

Because of this strong influence of regional climate on the Poyang Lake level and water resources, the hydrologic processes in the basin and the catchment discharge to Poyang Lake are expected

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to change in the future climate (Guo et al., 2006). To understand these possible changes and reduce the vulnerability of the basin to future droughts and floods, it is essential to understand how regional climate change would affect the inflows from the lake catchment to the lake and cause water resources change in Poyang Lake.

Predictions of future climate from General Circulation Models (GCM) have been downscaled to regional and local scales, and the downscaled data have been used to calculate changes in hydrological processes using various methods including hydrological models. For example, Akhtar et al. (2008) estimated water resources changes in three river basins in the Hindukush–Karakorum–Himalaya region using the HBV model driven by climate change scenarios. Marie et al. (2008) used the HSAMI model and simulated stream flow in a Nordic catchment in different climate scenarios, assessing potential impacts of climate change on local hydrology. Liu et al. (2008) forecasted the water level of Qinghai Lake in western China using the SWAT model and downscaled climate predictions from the ECHAM5 model.

This study uses a similar method. The objective of the study is to apply a whole-of-catchment hydrological model and investigate variations in inflows from the Poyang Lake catchment to the lake and subsequent changes in lake's water level in various climate scenarios. The future climate conditions in the Poyang Lake catchment will be downscaled from the ECHAM5 model. A catchment modeling approach, advanced from previous hydrological modeling methods, will be used in this study. This new approach will use a recently developed catchment hydrological model that treats the entire lake catchment of multiple sub-river basins as one integrated system. This new model overcomes the uncertainty associated with the simple linear addition of sub-river basin effects on lake hydrology and water level applied in previous Poyang Lake studies (e.g., Guo et al., 2008b; Su, 2008; Liu and Zhang, 2009). This integrated approach is more relevant for gaining better understanding of interactive and feedback processes among the sub-river inflows and their linear and non-linear effects on change in the Poyang Lake level and floods and droughts in the lake basin, improving understanding of the physiographic control on catchment discharge (Tate et al., 2004; Gibson et al., 2006).

The rest of this paper is organized as follows. The next section (Section 2) provides details of the study area and the data used in this study. Section 3 outlines the climate change scenarios and predicted future climate for the Poyang Lake catchment downscaled from the ECHAM5 model. The integrated hydrological model that will simultaneously simulate 5 sub-river basins and the floodplains in the Poyang Lake catchment also will be described in Section 3. Major results of this study are presented and discussed in Section 4, and the conclusions are summarized in Section 5.

2. Study area and available data

Poyang Lake is located within 28°22′–29°45′N and 115°47′–116°45′E and connects with the Yangtze River in the north (Fig. 1). The catchment has a subtropical wet climate characterized by a mean annual precipitation of 1680 mm and an annual average temperature of 17.5 °C. The topography varies from highly mountainous (maximum elevation of about 2200 m above the sea level) to alluvial plains in the lower reaches of the primary watercourses. Poyang Lake receives water flows from five rivers: Ganjiang, Fuhe, Xinjiang, Raohe and Xiushui, and exchanges water with the Yangtze River. Lake storage and lake level variation is controlled by catchment discharges and interactions with the Yangtze River (Hu et al., 2007). Each year, the lake experiences large water level fluctuations (>10 m) in response to annual cycle of precipitation. In the wet season in spring and early summer, the lake level rises and lake coverage expands, covering an area of roughly 170 km from the north to the south and 17 km from the east to the west (about 3800 km^2) (Xu et al., 2001). The lake shrinks to little more than a river during the dry season from late August through the winter months, exposing extensive floodplains and wetland areas which support migrating waterfowls and a variety of invertebrate species.

Land use across the catchment consists of forest (46%), shrub land (25%), crop land (25%) and small areas of pasture, urban centers and open water. The forest and shrub areas are dominated by various combinations of deciduous pine, fir, beech, and bamboo. Variability in vegetation canopy is an important factor in the hydrological functioning of the catchment (Finch, 1998; McJannet et al., 2007). In this study, the Leaf Area Index (LAI) data were used to measure the canopy. The data were derived using monthly average NOAA-AVHRR-NDVI (U.S. National Oceanic and Atmospheric Administration–Very High Resolution Radiometer–Normalized Difference Vegetation Index) data in the period from January 1995 to September 1996 and from October 1999 to June 2000. The monthly average LAI values are 0.32–2.72 for agricultural crops, 1.06–3.54 for forest, 0.84–3.12 for shrub, 0.30–1.72 for pasture, and a constant 0.07 for urban areas.

The soils in the catchment were classified according to the Genetic Soil Classification of China, and soil distributions were obtained from national soil survey at a resolution of 1:1,000,000 (Gong et al., 1999; Shi et al., 2006). Eight major soil types are identified in the catchment and have the following aggregated proportions: red soil (43%), latosol (23%), paddy soil (21%), yellow soil (7%), alluvial soil (3%), purplish soil (1.5%), yellow–brown soil (1%) and limestone soil (0.5%). Hydraulic properties of these soils were determined from the soil survey (Shi et al., 2004), with porosity ranging from 0.41 to 0.52, field capacity from 0.32 to 0.36, and saturated hydraulic conductivity varying from 0.14 to 0.97 m/d.

Groundwater extraction in the catchment is estimated to be about 8% of all water consumption (Zeng and Duo, 1997), although a lack of monitoring system precludes an accurate evaluation. Groundwater is speculated, based on the geology and topography of the catchment, to flow from the bordering mountains and associated fractured rock aquifer towards the low-lying alluvial aquifers associated with river systems and the fringe areas around the lake. Unfortunately, lack of piezometers within the catchment leaves these speculations unsubstantiated.

Inflows to Poyang Lake predominantly come from five main rivers: Ganjiang, Fuhe, Xinjiang, Raohe and Xiushui (Fig. 1). Six gauging stations on these rivers collect surface flows from 77% of the lake's catchment area. The averaged annual flow rates at these gauges (including two gauges on the Ganjiang River) are shown in Table 1. The total average annual discharge from all gauged rivers was 1112×10^8 m^3/year (equal to a specific discharge of 895 mm/year) in the period from 1960 to 2002. Because of the significant seasonal variability in the discharge from the 5 rivers, e.g., an average of 59% of the annual discharge arriving between March and June, many reservoirs and irrigation systems have been constructed in the Poyang Lake catchment to provide a leeway of water supply in dry months. These include Zhelin Reservoir (79×10^8 m^3) on the Xiushui River, Wan'an Reservoir (22×10^8 m^3) on the Ganjiang River, and Hongmen Reservoir (12×10^8 m^3) on the Fuhe River (see Fig. 1). Some of these reservoirs' data were used in this study.

Meteorological data used in this study were from 14 national meteorological stations inside the catchment (see Fig. 1). They measured daily precipitation, temperature, solar radiation, wind speed, and relative humidity. The observed records used in this study are from 1961 to 2000. In addition, climate data predicted by the ECHAM5, a fully coupled atmosphere and land surface model developed at the Max Planck Institute for Meteorology in Germany (Schulz et al., 2001; Roeckner et al., 2003), were acquired and used

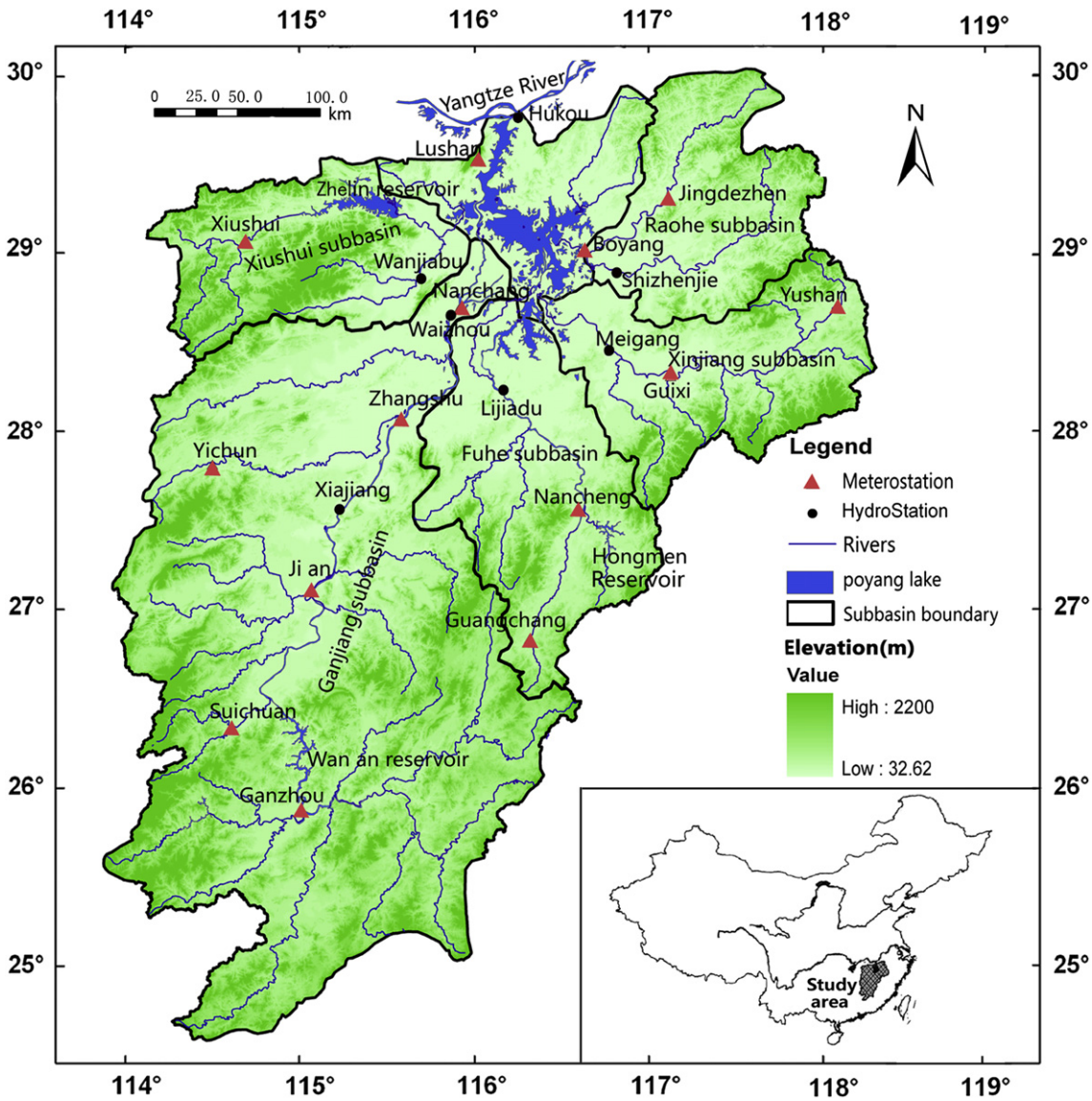

Fig. 1. Topography and stream systems of the Poyang Lake catchment. Stream gauging stations ("Hydrostation") and meteorological stations ("Meterostation") are marked.

to downscale the future climate in the Poyang Lake catchment. The ECHAM5 output was chosen for this study because the model has been shown successfully simulating the historical climate from 1941 to 2000 in the Yangtze River basin (Su et al., 2007). The model was used to predict the climate for the first 50 years of the 21st century under the three carbon dioxide emission scenarios: SRES-A2 (high emission), A1B (mid-range emission) and B1 (low emission) (IPCC, 2007). The ECHAM5 output has an equivalent horizontal resolution of $1.875^\circ \times 1.875^\circ$, and has 19 or 31 layers in the vertical direction. The model has 7 grid points inside the Poyang Lake catchment. Predictions of climate variables at these 7 grid points were used in downscaling to generate future climate scenarios for the catchment.

3. Methodology

3.1. Downscale of the ECHAM5 output

The "Delta change approach" (e.g. Arnell, 1998; Middelkoop et al., 2001; Marie et al., 2008) was used to downscale the ECHAM5 output of future climate to the Poyang Lake region. In this method, it assumes that the temporal and spatial structure of historical precipitation and temperature will not change in the future, only the magnitude of fluctuation will change. Under this assumption, the daily temperature in the future, $T_{f,d}$, is calculated using both model simulated historical temperature and predicted temperature,

$$T_{f,d} = T_{o,d} + \left(\overline{T_{f,m}} - \overline{T_{b,m}}\right) \quad (1)$$

where $T_{o,d}$ is the observed daily temperature of a year, $\overline{T_{f,m}}$ is the ECHAM5 predicted mean temperature of the month in which the daily temperature is calculated, and $\overline{T_{b,m}}$ is the ECHAM5 simulated mean monthly temperature for the period from 1961 to 2000.

Similarly, future daily precipitation, $P_{f,d}$, is constructed from

$$P_{f,d} = P_{o,d}\frac{\overline{P_{f,m}}}{\overline{P_{b,m}}} \quad (2)$$

where $P_{o,d}$ is observed daily precipitation of a year, and $P_{f,m}$ and $P_{b,m}$ have similar meanings as $\overline{T_{f,m}}$ and $\overline{T_{b,m}}$ but for monthly

Table 1
Poyang Lake gauging stations.

Gauging station (period of record)	Location	Confluence area ($\times 10^4$ km^2)	Average annual discharge ($\times 10^8$ m^3/year)	Specific discharge (mm/year)
Waizhou (1960–2002)	Ganjiang River (Lower)	8.10	695	858
Xiajiang (1960–2002)	Ganjiang River (Middle)	6.27	526	839
Lijiadu (1960–2002)	Fuhe River	1.58	127	804
Meigang (1960–2002)	Xinjiang River	1.55	182	1174
Shizhenjie (1980–2002)	Raohe River (Le'anjiang branch)	0.84	100	1190
Wanjiabu (1960–2002)	Xiushui River (Liaohe branch)	0.36	36	1000

precipitation. Although this downscaling method contains uncertainties particularly for precipitation, Reynard et al. (2001) show that downscaled data from this method can describe regional climate variations reasonably well.

This downscaling method was used to obtain the climate conditions in the Poyang Lake catchment for 2011–2050 under the A1B, A2, and B1 climate change scenarios. The differences of the 2011–2050 mean monthly temperature and precipitation from the current climatology (1961–2000) are shown in Fig. 2. They indicate warmer temperature in 2011–2050 under all three climate change scenarios. The range of monthly temperature increase is 0.51–1.42 °C for A1B scenario, 0.59–1.83 °C for A2, and 0.56–1.75 °C for B1. In all three scenarios the increase in temperature is larger from November to February than in the other months of the year, a result indicating warmer winters in the future.

Precipitation change shows more complex patterns than temperature. Mean annual precipitation during 2011–2050 shows increase by 1.6% and 2.8% for A1B and B1 scenarios, respectively, but decrease by 2.7% in A2 scenario. In all three scenarios, monthly precipitation increases in April–August, with the largest increase in June and July. Monthly precipitation decreases from September to February, with the largest decrease in September for A2 (−31.7%) and B1 (−24.9%), and in December for A1B scenario (−19.0%).

These downscaled future climate conditions will be used in the modeling study to evaluate the climate change effects on the catchment inflow to Poyang Lake and the lake water level change.

3.2. Catchment modeling

The Poyang Lake catchment is a heterogeneous composite of 5 sub-river catchments. Evaluation of Poyang Lake hydrology requires a hydrological model that has the capacity to simulate complex spatial and temporal variability in surface and groundwater flows. The vast area of the multi-river catchments and relatively sparse monitoring stations post additional challenges for such modeling effort, and also demand for computational efficiency of such models. The WATLAC model (Fig. 3) developed by Zhang and Werner (2009) has the capacity to meet these challenges and is used in this study to simulate and understand the Poyang Lake catchment hydrology.

WATLAC is a spatially distributed hydrological model with unique and effective computational techniques to simulate complex spatial variability of surface and subsurface flows (e.g., Zhang and Li, 2009). The model describes surface hydrological processes, soil water dynamics, and groundwater dynamics (Fig. 3). Overland flow, stream flow and saturated groundwater flow are simulated in the model. The model has been successfully applied to quantifying the impacts of changes in land use and climate on the catchment hydrological processes and inflows to lakes (Zhang and Werner, 2009). The details of the model are provided in Zhang and Li (2009) and Zhang and Werner (2009) and not repeated here.

Applying this model to the Poyang Lake basin used 4 km × 4 km grid resolution. Climate variables used to drive the model are from daily meteorological data of the 14 climate stations in the catchment. These climate data along with vegetation and soil data were interpolated to model grids using a Geographical Information System (GIS) method. Because of lack of subsurface information, the groundwater system was presumed to comprise a simple single-layer, shallow unconfined aquifer, which served as a pathway for rainfall infiltration to return to streams as base flow.

WATLAC currently does not have an automated parameter estimation algorithm. Thus, a trial-and-error method was used to calibrate the model in the basin. The performance of the model was evaluated using statistical analyses of model outputs. Statistical parameters, e.g., coefficient of determination (R^2) and Nash–Sutcliffe efficiency (E_{ns}) (Nash and Sutcliffe, 1970), were used to measure the capability and reliability of the model in describing the observed processes. In addition, for evaluation of systematic over or under estimation in model simulation, the relative error (R_e) also was analyzed,

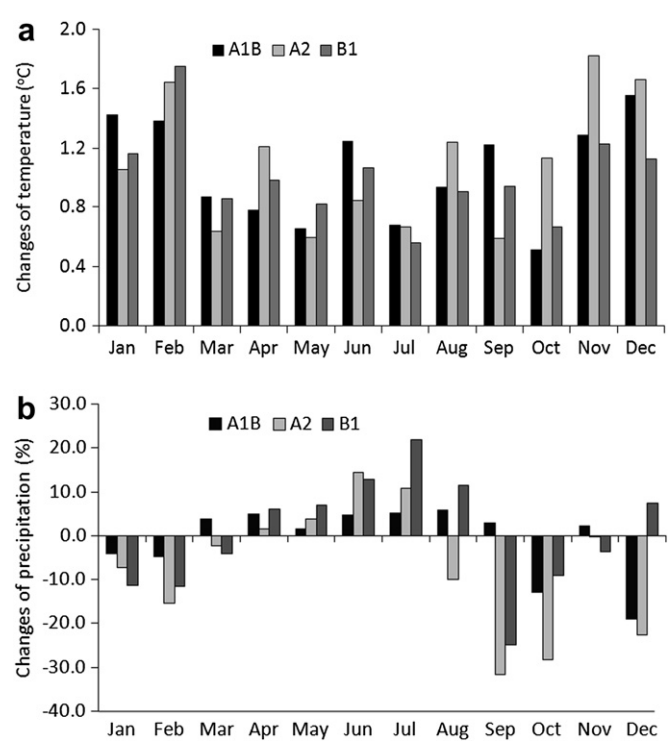

Fig. 2. Changes of predicted averaged 2011–2050 temperature (a) and precipitation (b) for the three climate scenarios in Poyang Lake catchment, relative to the mean of 1961–2000.

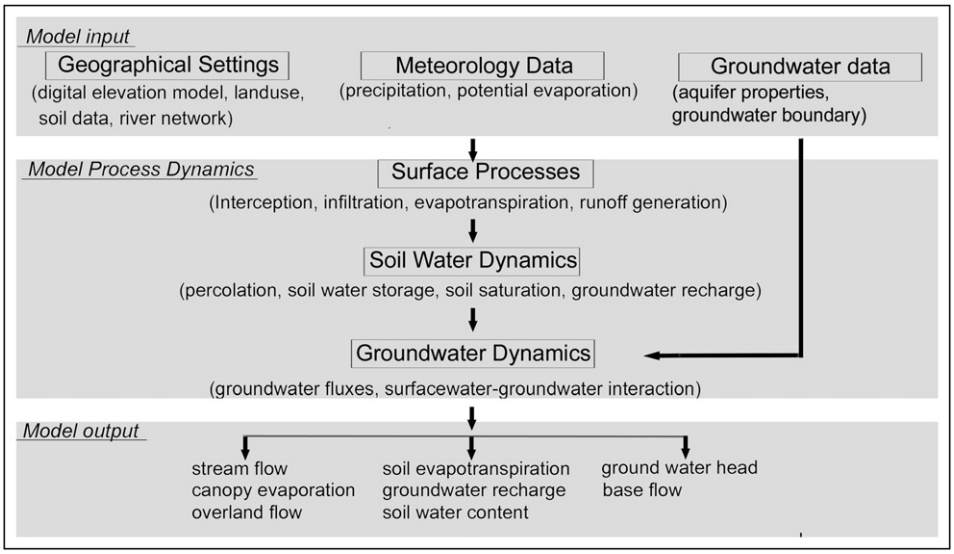

Fig. 3. Flow chart of the WATLAC model.

$$R_e = \frac{\sum_{i=1}^{n}(P_i - O_i)}{\sum_{i=1}^{n} O_i} \times 100\% \quad (3)$$

In (3), n is the total number of measurements, P is simulated stream flow, and O is observed stream flow.

3.3. Calculation of lake level

Calculation of the lake level change in response to inflow variations in different climate scenarios used a regression model

$$H = 0.37T + 0.0047R + 5.79 \quad (4)$$

where H (m) is the Hukou station's monthly mean water level, which measures the Poyang Lake level, T (°C) is the monthly average temperature of the Poyang Lake catchment and represents a collective climate effect on the water level, and R (units: 10^8 m^3) is the monthly averaged discharge of the catchment to the Poyang Lake. The climate effect represented in the T-term in (4) includes increased (decreased) surface evaporation and rainfall at high (low) temperatures (e.g., Hu and Willson, 2000). Fig. 4a shows the correlation of the simulated and observed monthly lake level at Hukou station with an R^2 of 0.80, and Fig. 4b shows comparisons of simulated and observed average annual lake water level, both results indicating the fidelity of (4) in describing the lake level fluctuation.

4. Results and discussion

4.1. Model calibration and validation

The WATLAC model was calibrated and validated using the observed daily stream flow from the seven gauging stations listed in Table 2. The split-sample test was applied. In this test, the observed daily stream flow from 1992 to 2002 was divided into two roughly equal periods: 1992–1997 and 1998–2002. The former was used for model calibration and the latter for model verification.

Statistical results of model performance are summarized in Table 2. These results show the model producing an overall good fit, with E_{ns} ranging between 0.64 and 0.86 for streamflows at six gauging stations. Ganjiang is the largest among the 5 rivers and has the E_{ns} between 0.72 and 0.76 in calibration and 0.64–0.68 in validation. The model performed much better for Fuhe (Lijiadu station) and Xinjiang (at Meigang station) with higher E_{ns} (0.85–0.86) in both the calibration and validation period. For the other two rivers the model accuracy is moderately high as well.

In addition, the relatively high values of R^2 (from 0.70 to 0.87) show that the model can well describe the variation of the observed stream flow for the five rivers (Table 2). Model ability to describe the lake basin hydrology also was shown by the scattered diagrams in Fig. 5. In individual sub-river catchments, the model slightly overestimated the stream flow at Waizhou station and Lijiadu station, and underestimated the stream flow at the other gauging stations. Causes of these biases could be from the effects of big

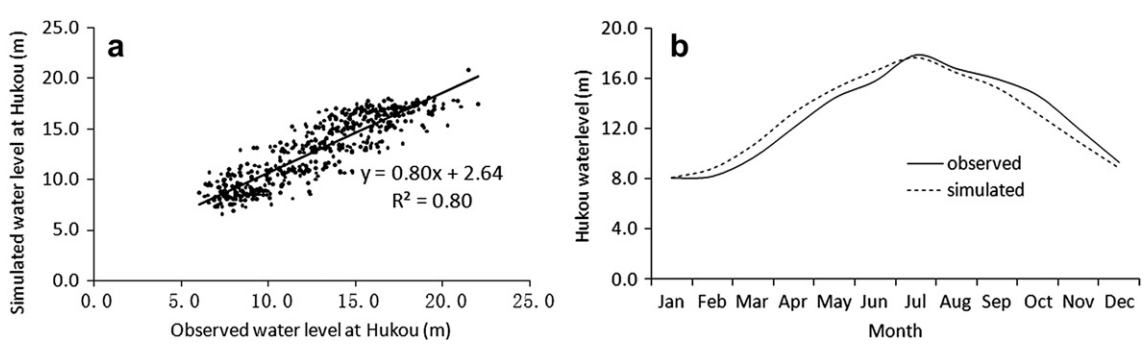

Fig. 4. Comparison of simulated and observed monthly lake level at Hukou gauging station from 1960 to 2003: (a) correlation of the simulated and observed monthly lake level, and (b) difference of simulated and observed monthly lake level.

Table 2
Calibration and validation result of daily stream flow at different gauging stations.

Gauging station	River sub-catchment	Calibration (Jan. 1993–Dec. 1997)			Validation (Jan. 1998–Dec. 2002)		
		E_{ns}	R^2	R_e (%)	E_{ns}	R^2	R_e (%)
Waizhou	Ganjiang	0.74	0.86	1.04	0.70	0.87	9.83
Xiajiang	Ganjiang	0.75	0.80	−13.72	0.68	0.81	−3.17
Lijiadu	Fuhe	0.85	0.86	16.42	0.85	0.85	8.70
Meigang	Xinjiang	0.86	0.86	−4.29	0.85	0.86	−4.38
Shizhenjie	Raohe	0.70	0.70	1.45	0.68	0.69	8.29
Wanjiabu	Xiushui	0.70	0.76	−12.58	0.70	0.76	−0.85

reservoirs in those river basins. Regulations of river flows by those reservoirs changed the natural daily stream flow processes. Because of lack of reservoir operation data these effects were not considered in the model. Nonetheless, these calibration and validation results for the 5 sub-river basins indicate that the model is reasonably accurate in describing the catchments' rainfall–runoff behavior.

4.2. Climate change impact on inflows to Poyang Lake

The calibrated model was used to examine how the catchment inflow to Poyang Lake may change in response to the future climate and how such change may affect the lake level in the future, assuming that the basin discharge will continue to play the primary role in variation of the Poyang Lake water level in the wet season.

4.2.1. Effect on annual and spatial changes of catchment inflow

Fig. 6 shows cumulative annual total inflows to the Poyang Lake from the 5 sub-river basins in the three climate scenarios. They are

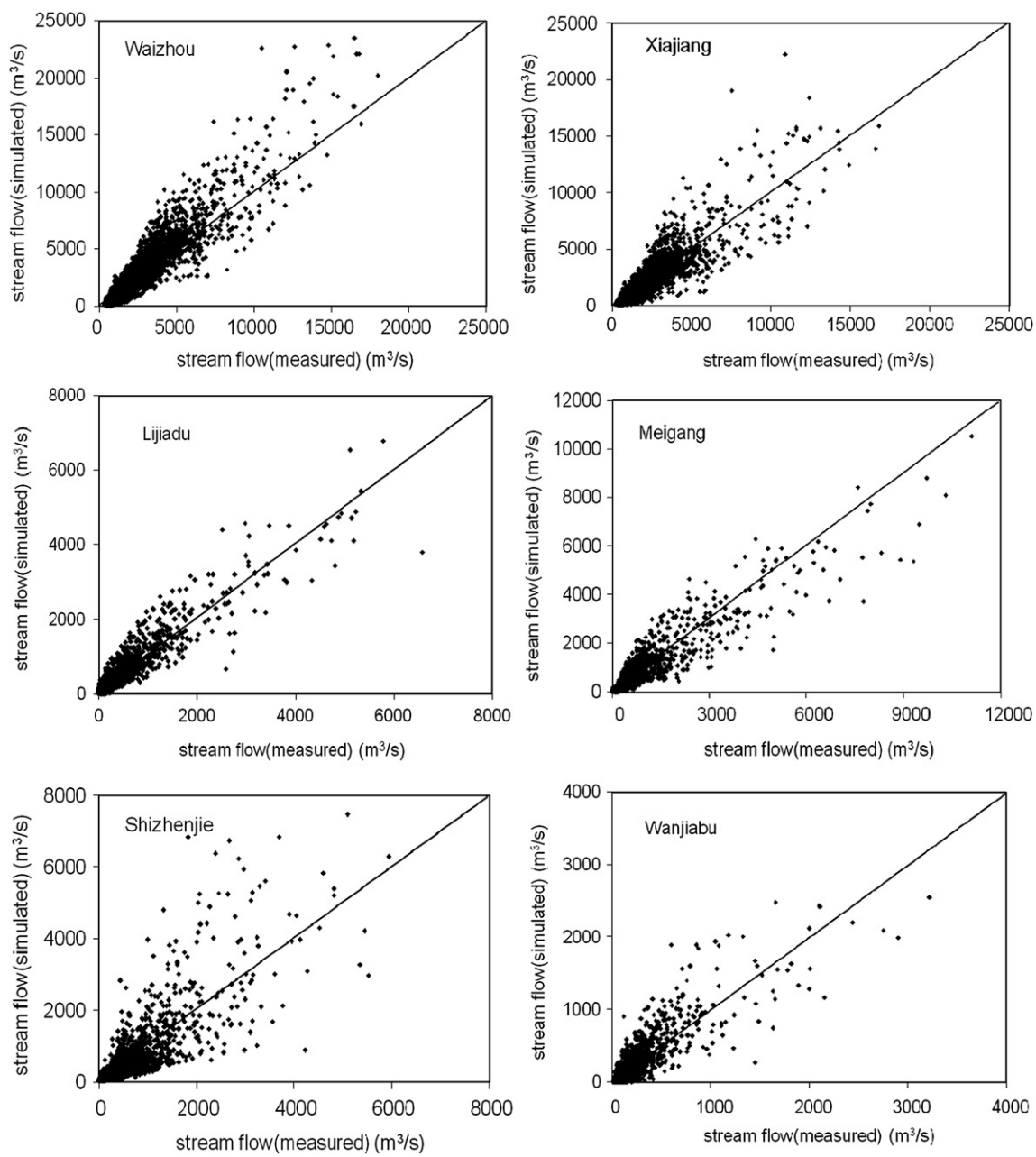

Fig. 5. Scatter diagrams of modeled stream flow against the measure stream flow for 1993–2002 at six gauging stations.

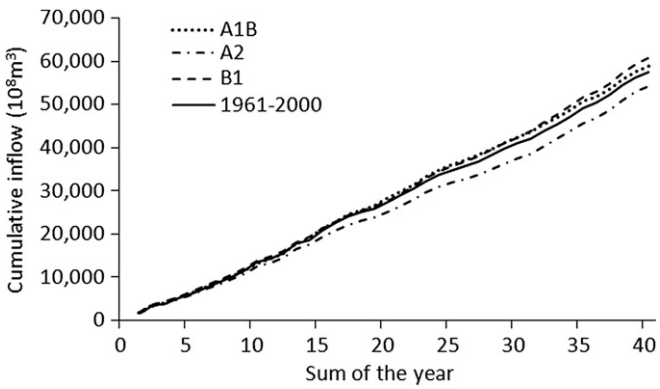

Fig. 6. Comparison of model cumulative annual catchment discharge in the three climate scenarios of 2011–2050 with the calculated result from historical data of 1961–2000.

compared to the observed inflow averaged for 1961–2000. The latter was calculated by summing the products of observed annual stream flow from an individual river basin and the ratio of the gauged basin area over the entire Poyang Lake catchment area. The cumulative curve in Fig. 6 indicates that the modeled total annual inflow in A1B and B1 scenarios is greater than the current inflow, while the inflow in the A2 scenario is smaller than the current inflow. Relative to the 1961–2000 inflow, the average annual inflow increases by 2.9% and 6.5% for A1B and B1 scenarios, respectively, and decreases by 5.2% in A2 scenario. In the total amount of catchment inflow, about 92% comes from the five rivers, and the rest is from the overland flow of the lake's floodplain.

The differences of the average annual water discharge from individual rivers in the three climate scenarios are shown in Fig. 7. Relative to 1961–2000 record, river discharge from all the five sub-river catchments increased in B1 scenario. The smallest increase is 3.2% from the Ganjiang river-catchment and the largest increase is 13.8% from the Raohe river-catchment. Increasing discharge is also shown in A1B scenario, except for Xinjiang river-catchment. In A2 scenario, decreasing inflow is found in Xiushui (−3.2%), Ganjiang (−5.4%) and Xinjiang (−13.6%) river-catchments, however. Fuhe and Raohe river-catchments have weak increase in discharge in the A2 scenario. These results indicate different responses of the water generation processes in these different river catchments of the Poyang Lake basin in the three climate change scenarios.

4.2.2. Effect on monthly and daily duration of catchment inflow

Statistical analysis indicates that inflow from the catchment to the Poyang Lake during the wet season from March to June is 61.2%,

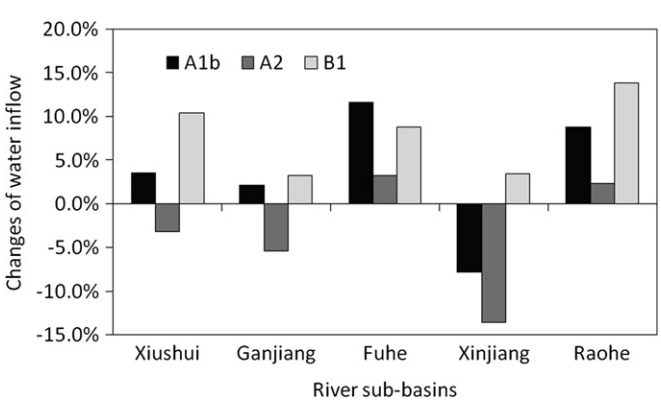

Fig. 7. Relative changes of annual discharge from the five sub-catchments in the three climate scenarios of 2011–2050 compared to 1961–2000.

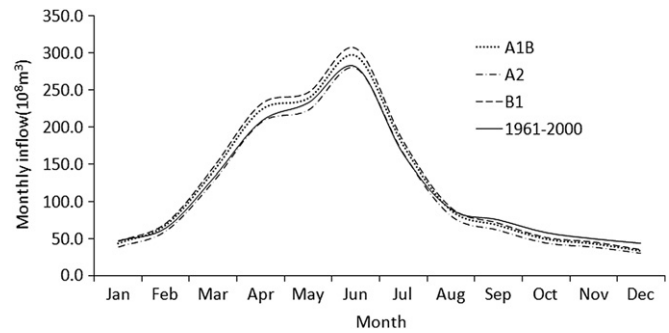

Fig. 8. Comparison of simulated catchment inflow averaged for 2011–2050 in the three climate scenarios with the calculated historical catchment discharge of 1961–2000.

61.7% and 61.2% of their total annual inflow in A1B, A2, and B1 scenarios, respectively. These discharge percentages are higher than the historical record of 58.8% during 1961–2000. The future annual distribution pattern in Fig. 8 indicates larger or equal discharge to the lake in the wet season and smaller discharge in the dry season. These changes may result from interactions of hydrological processes in the catchment with precipitation changes which increase during the wet season and decrease in the dry season.

As further shown in Fig. 9 of flow duration curve, which provides a graphical view of the overall changes associated with daily catchment inflow to the lake, there is an increase in daily inflow from Q_5 (the inflow is exceeded 5% of the time) to Q_{50} (the inflow is exceeded 50% of the time) compared to the historical flow amount, especially in A1B and B1 scenarios. However, significant decrease was shown from Q_{50} to Q_{95} (the inflow is exceeded 95% of the time) for all the three climate scenarios. Because Q_5 and Q_{95} can be considered as the extreme low inflow and flood peak inflow, changes in Q_5 and Q_{95} suggest the increase of extreme flood peak flow and decrease of base flow in the Poyang Lake catchment in future climate. These changes will directly affect the frequency and severity of floods and droughts in Poyang Lake.

4.2.3. Changes of lake level

In response to the changes of annual catchment inflow, Poyang Lake water level also changes. According to the regression model (4), future water levels for the three climate scenarios were calculated. As shown in Fig. 10, water level at Hukou station will increase by 0.06–1.10 m and 0.31–1.34 m from January to July for A1B and

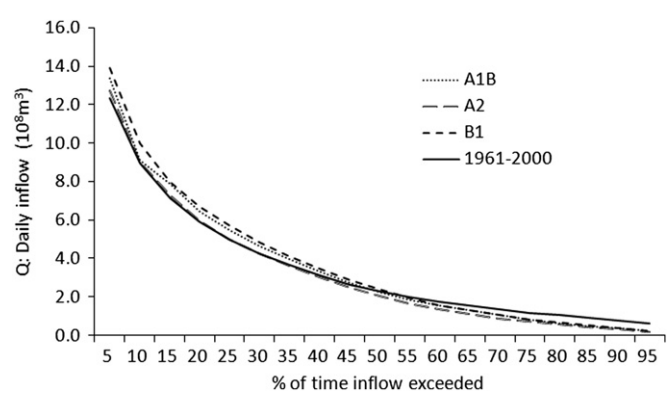

Fig. 9. Comparison of simulated daily inflow averaged over 2011–2050 in the three climate scenarios with the calculated daily watershed inflow and the historical inflow in 1961–2000.

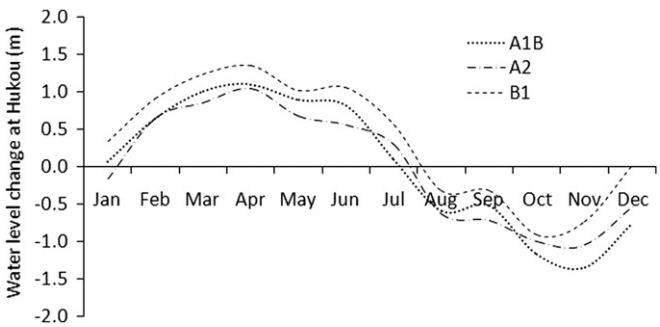

Fig. 10. Possible change of monthly lake level for 2011–2050 compared to that for 1961–2000.

B1 scenarios, respectively, and it will increase by 0.29–1.04 m from February to July for A2 scenario. However, water level at Hukou station will decrease by 0.32–1.31 m from August to December under the three climate scenarios. Average monthly increase of lake water level in the wet season (from March to August) is 0.55 m, 0.46 m, 0.81 m and average monthly decrease of lake water level in the dry season (from September to February) is 0.52 m, 0.47 m, 0.12 m in A1B, A2, and B1 scenarios, respectively.

The maximum increase of the lake level is predicted to happen in April and maximum decrease is in October or November. Increasing lake level in the wet season will increase the potential for severe flooding especially in July because July is the month when the lake level reaches the highest mark. Decreasing lake level will likely to elevate the drought severity in Poyang Lake basin and worsen the difficulty of water supply. To summarize, these predicted changes of the lake level suggest higher frequency and severity of floods in the summer and more severe droughts in autumn and winter seasons in the future climate. It is noted that the lake level calculated by (4) is somewhat overestimated for the wet season, but underestimated for the dry season. Therefore, the interpolation of the water level change in Fig. 10 may tend to overestimate the severity of floods and droughts.

5. Conclusions

This study extended the previous studies by applying a large-scale distributed hydrological model, WATLAC, to the entire Poyang Lake catchment to evaluate its inflow to the Lake under different climate change scenarios. The major advantage of the WATLAC is its effective computational methods that allow the model to take on large catchment with multiple river basins. The model also includes methods to calculate direct overland flows to Poyang Lake from the surrounding hill slopes, which have been neglected in previous studies. Quantitative assessments of the calibration and validation demonstrate the appropriateness and accuracy of this model for the study basin.

The daily outputs of ECHAM5 from 2011 to 2050 in three greenhouse gas emission scenarios (A1B, A2 and B1) were downscaled to the lake basin and used to drive the WATLAC model. The future climate in the basin is predicted to have an increased mean monthly temperature ranging from 0.51 to 1.42 °C, 0.59–1.83 °C and 0.56–1.75 °C for the A1B, A2 and B1 scenarios, respectively, relative to the climatology of 1961–2000. The annual mean precipitation is predicted to increase by 1.6% and 2.8% for the A1B and B1 scenarios, respectively, and to decrease by 2.7% for the A2 scenario, relative to the 1961–2000 climatology. Under these different climates, simulations show that annual catchment inflow to Poyang Lake is to increase by 2.9% and 6.5% for the A1B and B1 scenarios, respectively, but decrease by 5.2% for A2 scenario. Changes of monthly catchment inflow to the lake will cause increases in lake level in the range of 0.10–1.34 m from February to July and a decrease of water level in the range of 0.32–1.31 m from August to December under the three scenarios. These predicted changes suggest that there may be increases in frequency and severity of flooding and droughts in the Poyang Lake catchment in future climate.

Some uncertainties of this study include the accuracy of the GCM outputs, the delta change approach used in downscaling and the simple regression model used to calculate the lake water level from predicted climate and discharge of the Poyang Lake basin. Further work is needed to refine this research, including uncertainty analysis of the GCM outputs, the more rigorous mathematical representation of the dynamics of the lake water level and the influence of the Yangtze River.

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