Hydrological Modeling of High Mountainous Issyk-Kul Lake Basin

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The water resources system in Central Asia is under stress due to multiple interrelated drivers. The water supply from seasonal snow and glacial melt is already impacted by climate change, and water demands continue to increase with population growth and land-use change.

Issyk-Kul Lake is the tenth largest lake in the world by volume (1783 km^3). It is endorheic, with a relatively consistent low irrigation rate, and water outflow from the catchment is mainly driven by evapotranspiration. Located at 1607 meters above sea level, the catchment represents the typical High Mountainous Watershed of Tian-Shan or the so-called Northern Himalaya. Due to its endorheic nature, the lake surface fluctuations can validate hydrological processes in the catchment, including snow and glacier melt. However, scarcity of available observed data and complex terrain challenges model performance evaluation. Evaluation of reanalysis and gauge-based precipitation products is thus essential in improving the accuracy of forcing data for hydrological and land surface models (LSMs).

Satellite-based reanalysis data, especially in the mountainous areas, need bias correction that requires continuous long-term observed data. Kyrgyzstan, the former part of the Soviet Union, had been conducting local observations since the 1950s, but after collapse of the Soviet Union, only one-third of stations continued to operate, so there is a lack of data since the 1990s. Nowadays, newly installed meteorological stations start their operation; however, thir observation period is short and is not enough for continuous analysis.

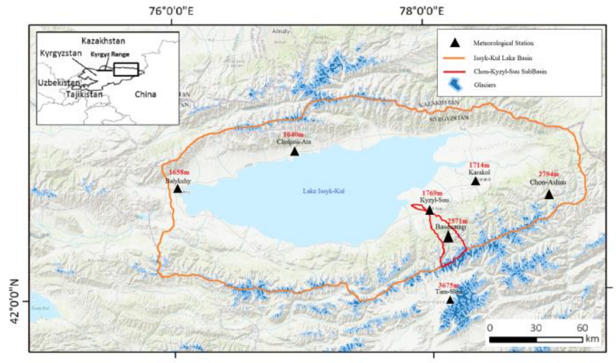

Fig. 1. Location of Issyk-Kul Lake Basin and spatial distribution of glaciers from Randolph Glaciers Inventory (RGI 6.0).

Precipitation data of five meteorological stations located in Balykchy, Cholpon-Ata, Kyzyl-Suu, Karakol, and Chon-Ashuu were compared with global precipitation products: JRA-55, ERA-5, APHRODITE, GSMaP, and GPCC. The performance of the products was evaluated by Pearson correlation factor and value difference using RMSE. No precipitation product showed a significant correlation with observed data. ERA-5 has shown a better value, but only for the single event values. It is possibly due to the limitation of the station equipment's measurements, as precipitations with less than 1 mm are not detected but are abundant in reanalysis products. The resolution of precipitation products is important for regional scale modeling.

Analysis of the Pearson correlation and RMSE of different reanalysis products is shown in table 1. Some of these products usually include in-situ observation data; that is why GPCC, APHRODITE, and GSMaPv6 can outperform other datasets.

Dataset	KZLS	KRKL	BLKC	CHAS	CHAT
ERA5 (RMSE)	0.53 52.8	0.59 37.0	0.55 46.2	0.63 31.7	0.44 39.0
JRA55 (RMSE)	0.44 36.4	0.45 34.9	0.41 48.6	0.49 26.4	0.35 37.3
GSMaPv6 (RMSE)	0.48 19.4	0.49 23.2	0.33 22.9	0.48 31.1	0.37 28.9
APHRO (RMSE)	0.43 23.3	0.46 25.8	0.33 15.0	0.54 38.3	0.3 22.9
GPCC (RMSE)	0.43 7.5	0.43 17.9	0.43 19.4	0.51 16.9	0.37 18.1

Table 1. Analysis of Pearson Correlation and root mean squared error (RMSE) among 5 stations: KZLS – Kyzyl-Suu; KRKL – Karakol; BLKC – Balykchy; CHAS – Chon-Ashuu; CHAT – Cholpon-Ata

GPCC shows the best results but is limited with the resolution of (1^ox1^o) for daily precipitation. This resolution doesn't provide enough accuracy for the mountainous catchment with complex terrain.

Orography impact on precipitation distribution is crucial in this study, though reanalysis products are inaccurate in regional scale precipitation estimation for mountainous regions. APHRODITE precipitation product has shown good applicability in water related studies, and its algorithm considers orography in the estimation of precipitation from in-situ stations. This approach can be useful for mountainous regions and particularly for this study. Precipitation distribution based on 6 observation stations with a resolution of 5km was created for Issyk-Kul Lake Basin and compared to other global products.

State-of-the-art Land Surface Models are used as effective, physically based models to describe land surface processes. In this study, SiBUC model is used to evaluate hydrological components of the water cycle. Water level fluctuation of the lake is estimated using Rainfall-Runoff Inundation Model, a kinematic model for runoff and evapotranspiration outputs from SiBUC.

Tian-Shan High Mountain Research Centre's observations data on Karabatkak Glacier since 2007 is also used to estimate glacier runoff. The methodology includes measurements of daily ablation stakes during a summer ice melting period. The observation scheme was further expanded to higher locations in the accumulation zone from 2013.

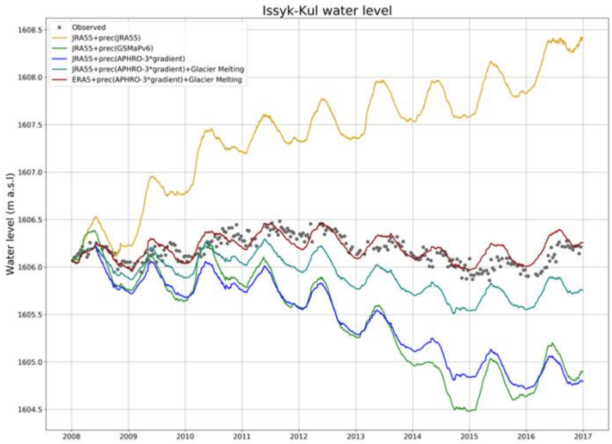

Fig. 2. Issyk-Kul Lake water level variations observed and modeled

Figure 2 shows JRA55 precipitation product overestimates overall precipitation for the whole catchment, and GSMaPv6 underestimates. APHRO-3 precipitation dataset includes in-situ meteorological station data using APHRODITE algorithms for interpolation. *gradient is an altitude coefficient for precipitation in high elevation.

The model runs using JRA55 forcing data (temperature, humidity, air pressure, wind speed, downward radiation) shows a slight underestimation in overall water level fluctuation. It can be affected by the output component of the water balance, which is evapotranspiration. Results are improved with the dataset from ERA5 forcing data. The best result is found using an effective combination of various reanalysis products and incorporated simple glacier component.

This study shows that hydrological modeling of high mountainous areas is very challenging in terms of data availability and consideration of various water balance components. The efficiency of global products on the regional scale, especially remote ungauged areas, may not give precise results and proper downscale approaches should be implemented in order to improve accuracy of the input data.