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Hydrological Modeling of Glacier-fed 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 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 so-called Northern Himalaya. Modeling and validation of the lake surface fluctuations provide an understanding of hydrological processes in the catchment, including snow and glacier melt with a minimum of uncertainty; it will further help assess climate change impact on the basin. However, due to the scarcity of available observed data and complex terrain, it is challenging to assess model performance at its best. 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 a continuous long period 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, more and more meteorological stations start their operation, but it is not enough for continuous analysis.

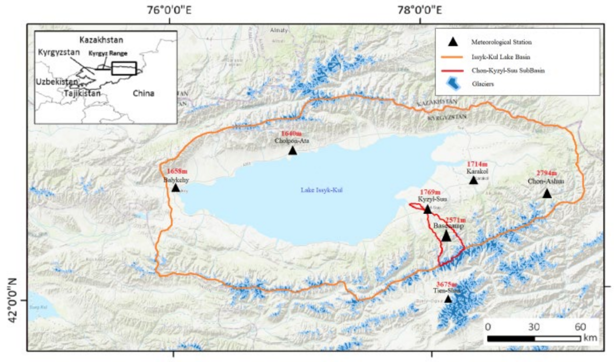

Fig. 1. Location of Issyk-Kul Lake Basin and spatial distribution of glaciers from Randolph Glaciers Inventory (RGI 6.0).

Analysis of the Pearson correlation and RMSE of different reanalysis products compared with meteorological stations 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	0.53	0.59	0.55	0.63	0.44
(RMSE)	52.8	37.0	46.2	31.7	39.0
JRA55	0.44	0.45	0.41	0.49	0.35
(RMSE)	36.4	34.9	48.6	26.4	37.3
GSMaPv6	0.48	0.49	0.33	0.48	0.37
(RMSE)	19.4	23.2	22.9	31.1	28.9
APHRO	0.43	0.46	0.33	0.54	0.3
(RMSE)	23.3	25.8	15.0	38.3	22.9
GPCC	0.43	0.43	0.43	0.51	0.37
(RMSE)	7.5	17.9	19.4	16.9	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

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 measurement 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.

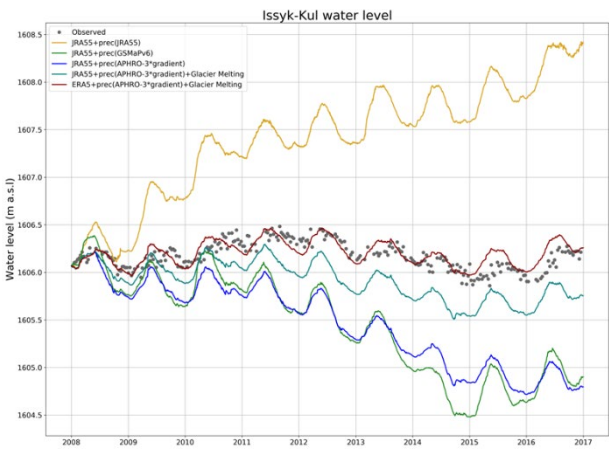

Fig. 2. Issyk-Kul Lake water level variations observed and modeled

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 run 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.

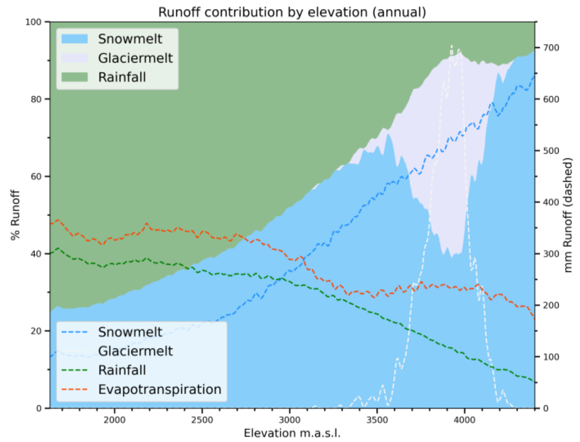

Fig. 3. Runoff components contribution by elevation in Issyk-Kul Lake Basin

A multi-year analysis of basin water balance has shown relative contribution of icemelt as 7.23%, snowmelt as 35.54% and rainfall as 57.23%. Rainfall is dominant over lake and melting glaciers become crucial over altitude of 3300 m (Fig.3).

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.