COMPARISON OF HYDROLOGICAL MODELS TO DETERMINE FLOOD CHARACTERISTICS FOR THE TOKACHI RIVER, HOKKAIDO (JAPAN)

MARK HEGNAUER
Deltares, Delft, The Netherlands, mark.hegnauer@deltares.nl

TSUYOSHI HOSHINO
Hokkaido University, Sapporo, Japan, hoshino@eng.hokudai.ac.jp

TOMOHITO J. YAMADA
Hokkaido University, Sapporo, Japan, tomohito@eng.hokudai.ac.jp

ABSTRACT

In 2016 Hokkaido (northernmost island in Japan) experienced extreme rainfall, resulting in severe flood damage due to the four typhoons. Climate change is expected to increase the intensity of typhoons that will cause heavy rainfall in Hokkaido in the future. Better understanding the dynamics of these events, a modelling study is conducted to simulate past and future flood dynamics.

The study includes an ensemble meteorological events for past and future climate conditions. A set of over 8,000 events are used as input to multiple rainfall-runoff models. The ensemble of models includes both semi and fully distributed models and all cover the river basin of the Tokachi River. The models simulate the hydrological processes differently and differ in the level of detail they simulate these processes. The multi-model ensemble is used to investigate the importance of the different processes in the simulation of extreme flood events in Hokkaido. The results of the model comparison can be used to further develop the models to optimize their use in the flood risk assessment for Hokkaido and potentially Japan. The comparison is a joint effort of a consortium of researchers from Japan and The Netherlands.

Keywords: extreme events, hydrological model comparison, Hokkaido, flood risk, d4PDF

1. INTRODUCTION

In 2016 Hokkaido (northernmost island in Japan) experienced extreme rainfall, resulting in severe flood damage due to the four typhoons. Climate change is expected to increase the intensity of typhoons that will cause heavy rainfall in Hokkaido in the future. The previous study showed the risk of heavy rainfall over the Tokachi River basin due to tropical cyclone increases under warmer climate condition (Hoshino et al., 2020). Better understanding the dynamics of these events, a modelling study is conducted to simulate past and future flood dynamics.

2. DATA AND METHODOLOGY

2.1 Rainfall data

In this study, we utilized large number of flood events from the Database for Policy Decision Making for Future Climate Change (d4PDF) (Mizuta et al., 2017). The experimental settings of d4PDF consist of a past climatic condition and a 4 °C warmer climatic condition. To prepare rainfall data that accurately reflect basin and topography shapes with respect to the Tokachi River basin, the dynamical downscaling was conducted to convert annual maximum rainfall events to a horizontal resolution of 5 km (d4PDF-5km). Yamada et al., (2018) verified the validity of d4PDF-5km in terms of heavy rainfall characteristics. In order to calibrate the hydrological models, we used the Radar-AMeDAS data and the Water Information System managed by MLIT as observed rainfall data and discharge data, respectively.

2.2 Hydrological models

2.2.1 wflow_sbm

Wflow_sbm is a conceptual bucket-style hydrologic model based on simplified physical relationships and it uses kinematic wave surface and subsurface routing for lateral transport. The wflow_sbm model is a fully distributed hydrological model, allowing the use of high-resolution spatial input data. This makes the model well suited for the use of high-resolution climate model output, such as presented in Section 2.1. A schematic of the most relevant vertical and horizontal processes in the wflow_sbm concept are shown in Figure 1.
The wflow_sbm model for the Tokachi river basin was setup based on globally available data at a ~1x1 km_2 model resolution. The river network, river length and slope parameters are derived from the state-of-the-art hydro-MERIT dataset (Yamazaki et al. (2019)). The hydrological parameters for the soil are derived from the GLOBCOVER land cover map and the SoilGrids250m soil database. The parameters are derived and scaled to the model resolution using point-scale (pedo)transfer functions in combination with Multiscale Parameter Regionalization (MPR) techniques.

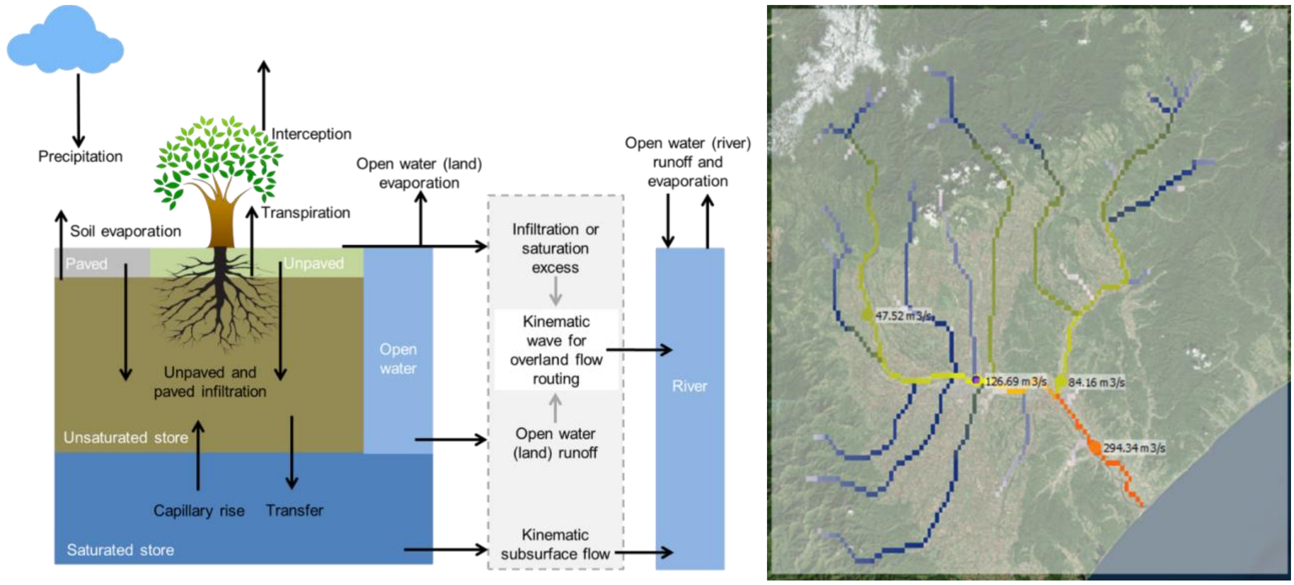

Figure 1. Schematic of the wflow_sbm concept showing the vertical and horizontal processes for a specific grid cell (left) and the river network of the wflow_sbm model (right).

2.2.2 HBV

HBV (Hydrologiska Byråns Vattenbalansavdelning) was developed at the Swedish Meteorological and Hydrological Institute (SMHI) in the early 1970s and has been applied to many river basins all over the world (Lindström et al., 1997). HBV is a conceptual model, which means that the model components represent real-world layout of the basin in such a way that the runoff generating processes are described realistically (Figure 2).

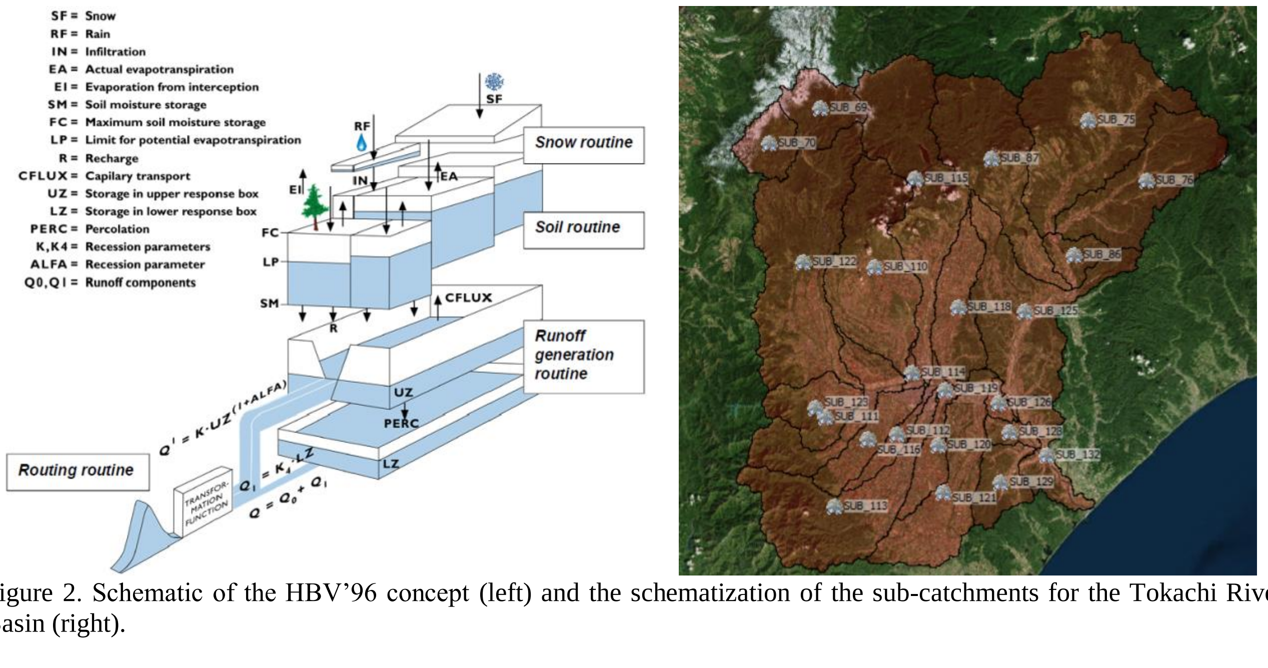

Figure 2. Schematic of the HBV'96 concept (left) and the schematization of the sub-catchments for the Tokachi River Basin (right).

The model layout can be divided into several routines. In the “snow routine” accumulation of snow and snow melt are determined according to the temperature. The "soil routine" controls which part of the rainfall and melt water forms excess water and how much is evaporated or stored in the soil. The “runoff generation routine” consists of an upper, nonlinear reservoir representing fast runoff components and a lower, linear reservoir representing base flow. Flood routing processes are simulated with a simplified Muskingum approach. More detailed information on the model structure and the various formulas are given in Lindström et al. (1997).
The schematization of the HBV’96 model for the Tokachi River Basin includes 24 sub-basins (see also Figure 2), which are linked to gather for the routing of the discharge from upstream to downstream using a simplified Muskingum routing routine (included in HBV). The reservoir behavior can be simulated in the model using a simplified reservoir routing module.

2.2.3 MATSIRO

The Minimal Advanced Treatments of Surface Interaction and Runoff (MATSIRO) (Takata et al., 2003) is used for this study. MATSIRO can simulate the exchange of water vapor, energy, and momentum between the land surface and atmosphere on a physical basis. The interaction between atmosphere and land surface can be simulated by this model with a general circulation model (GCM).

2.2.4 RRI model

Rainfall-Runoff-Inundation (RRI) model (Sayama et al., 2012) is a two-dimensional model for simulating rainfall-runoff and flood inundation simultaneously. This model simulates surface, sub-surface and vertical infiltration for slope cells, while river flow is simulated with one dimensional diffusive wave model.

3. RESULTS AND DISCUSSION

The heavy rainfall event in August 2016 was targeted in order to calibrate each hydrological model. Figure 3 shows the simulated result by RRI model at the point of the Tokachi dam. This figure shows observed discharge and simulated discharge of various parameters settings (Manning’s roughness parameter for river: 0.02, 0.03 and 0.04 $m^{-1/3}$ s, Manning’s roughness parameter for slope: 0.3, 0.4 and 0.5 $m^{-1/3}$ s, soil depth: 0.5, 1.0 and 1.5 m, lateral saturated hydraulic conductivity: 0.05, 0.10 and 0.15 m/s). The observed peak discharge is covered with simulated results. This result implies RRI model can be used to elucidate the flood risk with moderate parameter setting.

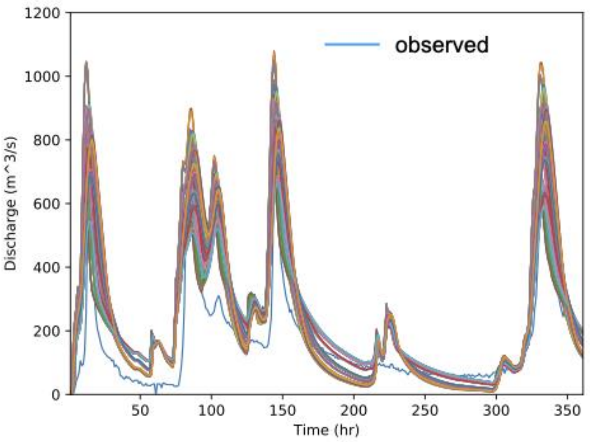

Figure 3. The inflow discharge at the Tokachi dam during August 17th, 2016 to September 1, 2016. The blue line and other lines indicate observation and simulated result (81 parameter settings), respectively. The horizontal axis indicates elapsed time [hr] from 00:00 (UTC), August 17th, 2016.

ACKNOWLEDGMENTS

The study has been made possible with funding of the Netherlands Enterprise Agency (RVO), River Center of Hokkaido, Docon Co., Ltd, Hokkaido University, Rijkswaterstaat, HKV Consultants and Deltares.

REFERENCES

Hoshino, T., Yamada, T. J., and Kawase, H. (2020). Evaluation for characteristics of tropical cyclone induced heavy rainfall over the sub-basins in the ensemble experiments. *Atmosphere*, *11*(435).

Imhoff, R., van Verseveld, W., Osnabrugge, B., A. Weerts (2019). Scaling point-scale pedotransfer functions to seamless large-domain parameter estimates for high-resolution distributed hydrological modelling: An example for the Rhine river, submitted to WRR, 2019.

Lindström, G., Johansson, B., Persson, M., Gardelin, M. and Bergström, S. (1997). Development and test of the distributed HBV-96 hydrological model. Journal of Hydrology, 201, 272-288.

Mizuta, R., Murata, A., Ishii, M., Shiogama, H., Hibino, K., Mori, N., Arakawa, O., Imada, Y., Yoshida, K., Aoyagi, T., et al. (2017). Over 5,000 Years of Ensemble Future Climate Simulations by 60-km Global and 20-km Regional Atmospheric Models. *Bull. Am. Meteorol. Soc.*, *98*, 1383–1398.

Sayama, T., Ozawa, G., Kawakami, T., Nabesaka, S., Fukami, K. (2012). Rainfall-Runoff-Inundation analysis of the 2010 Pakistan flood in the Kabul River basin, *Hydrological Science Journal*, 57(2), 298-312.

Takata, K., Emori, S., Watanabe, T. (2003). Development of the minimal advanced treatments of surface interaction and runoff. *Global and Planetary Change*, *38*(1–2), 209–222.

Yamada, T. J., Hoshino, T., Masuya, S., Uemura, F., Yoshida, T., Omura, N., Yamamoto, T., Chiba, M., Tomura, S., Tokioka, S., et al. (2018). The influence of climate change on flood risk in Hokkaido. Journal of Japan Society of Civil Engineers, Advances in river engineering, 24, 391-396. (in Japanese with English abstract)

Yamazaki D., D. Ikeshima, J. Sosa, P.D. Bates, G.H. Allen, T.M. Pavelsky (2019). MERIT Hydro: A high-resolution global hydrography map based on latest topography datasets, *Water Resources Research*, doi: 10.1029/2019WR024873.

Yamazaki, D., T. Oki., and S. Kanae (2009). Deriving a global river network map and its sub‐grid topographic characteristics from a fine‐resolution flow direction map, *Hydrol. Earth Syst*. Sci., 13, 2241‐2251.