Applications of a distributed hydrological model to the AWCI demonstration river basins

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Abstract In order to tackle extreme events such as floods, reliable weather forecast is required to input into land surface models to make sound decisions. In Asia the countries affected by these events recognized the need to establish the Asian Water Cycle Initiative (AWCI). The objective is to promote integrated water resources management by making usable information from Global Earth Observation System of Systems (GEOSS) to address the common water-related issues in Asia. Within this framework early successful results are achieved. For example, real-time flood management using quantitative precipitation forecast at meso-scale in Japan. Optimal dam operation was achieved maximizing the hydroelectricity production in The Philippines. Flood forecasting forced by meso-scale High Resolution Model in Vietnam. Flood simulation was obtained using corrected satellite rainfall data in Bangladesh. Optimal dam operation was achieved at Pampanga basin in The Philippines. The results might be useful as reference tools to the decision makers contributing to societal benefits.
Keywords Floods; AWCI; distributed hydrological model; Tone River; climate change impacts

INTRODUCTION

Extreme events usually occur due to large water cycle fluctuations at global and regional scales, while disasters and damages take place at local scale. The observations and predictions of the water-related hazards and their damages can be enhanced by combining global earth observation and prediction systems and local information.

There is a growing concern about impacts of the global warming in flood risks and the need to address them in a more coordinated way. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) summarized and projected the trends of precipitation in past and future in the following ways: "the frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapor."; and "It is very likely that heavy precipitation events will continue to become more frequent.", respectively (IPCC, 2007). The flood hazards will be intensified due to the global warming. We need timely, quality, long-term, global water cycle information as a basis for sound and effective flood risk management.

In Asia the cooperation among 18 countries has being established as Asian Water Cycle Initiative (AWCI). The objective is to promote integrated water resources management by making usable information from Global Earth Observation System of Systems (GEOSS) to address the common water-related problems in Asia. Four main water issues are targeted: floods, droughts, water pollution and climate change impacts on water cycle. The key points of AWCI are: convergence of satellite observations, data integration, open data and source policies, and capacity building. Under this initiative each member country proposed one demonstration River basin with observed hydro-meteorological data. According to the needs of each River basin management, a distributed hydrological model is set-up to take advantage of spatially distributed forcing data. Additionally, an optimization algorithm might be coupled to improve the efficiency of water resources management such as flood reduction, water allocation at dams, hydroelectricity, flood alarming and evacuation programs. Some of the early achievements are: optimal flood management of Upper Tone River in Japan using a dam network and Quantitative Precipitation Forecast (QPF) at meso-scale. Similarly, the optimal dam operation was achieved at Pampanga basin in The Philippines reducing the flood peaks downstream and also maximizing the hydroelectricity production. In Vietnam, the flood inundation at Hue City was predicted for flood alarming and preparedness using a High Resolution Model (HRM) with 6 hours lead-time. In Bangladesh, the discharge of the Meghna River basin was simulated using corrected satellite rainfall measurements from the Tropical Rainfall Measurement Mission (TRMM). All these results might be useful as reference tools to the decision makers contributing to societal benefits.

The objective of this paper is to introduce the flood management system applied in the AWCI demonstration basin in Japan in detail among all applications. Section two introduces the features of the distributed hydrological model as a component of the system. Section three summarizes the coupled system and results obtained in the Upper Tone River application.

METHODOLOGY

In order to meet the increasing societal needs for improving flood prediction, including the climate change impacts on the global to local water cycle variations, there are strong research efforts to apply hydrological models throughout the world for getting better understanding of water and energy cycle variations. Much of this work has involved coupling Distributed Hydrological Models (DHMs) with Land Surface Models (LSMs), since this coupling potentially improves the land surface representation, benefiting both the stream flow prediction capabilities of the hydrological models as well as providing improved estimates of water and energy fluxes into the atmosphere (Pietroniro and Soulis, 2003). This study employed the so-called Water and Energy Budget based-Distributed Hydrological Model (WEB-DHM), which couples the widely used SiB2 by Sellers et al. (1996), with a Geomorphology Based Hydrological Model (GBHM) developed at the University of Tokyo by Yang et al. (2002). The GBHM is a physically based model which was conceived to simulate large River basins but at low computational expenses. So far, the entire Yellow River, Yangtze River and Chao Phraya River were simulated successfully. One of the GBHM versions has embedded dam network operation within the river network using a mass balance function with a linear release function as introduced by Saavedra et al. (2006).

APPLICATION IN TONE RIVER

There is growing concerns on decision support tools which can effectively introduce the flood prediction with improved accuracy to decision making on flood control. In South-east Asia region, dam operation during tropical cyclones is crucial to reduce flood peaks down stream and maximize the water level at the reservoirs for different future demands. To overcome the control problem of dam operation, Labadie (2004) reported the benefit of heuristic programming models to find the global optima. Ngo et al. (2007) reported successful coupling of MIKE 11 and Shuffled Complex Evolution (SCE) by optimizing historical operation rule curves of Hoa Binh dam, Vietnam. The research focused on the trade-off between flood control and hydropower generation achieving optimized rule curves. However, it would also be interesting to include forecast data in the real-time operation. The present system focuses on effective flood control operation of a multi-purpose and multi-reservoir including the features below:

(a) quantitative rainfall prediction with the estimated prediction error to an optimization scheme;
(b) introduction of a physically based distributed hydrological model to address multi-reservoir by making maximum use of spatially distributed prediction rainfall; and
(c) introduction of multi-purpose optimization functions for getting a quantitative solution.

In order to reduce flood peaks downstream and store water at dams for future use a desirable discharge Q_{opt_gauge} is introduced as a constant value taking as reference the average discharge during flood period. Firstly, WEB-DHM is run to simulate discharge downstream without the dam effect, $Q_{without\_dam}$. If this value does not exceed the desirable discharge $Q_{desirable}$, the system is not activated. If opposite, the simulated discharge downstream with the dam effect Q_{with_dam} needs to be calculated. The potential flood volume $flood\_vol_{dam}$ to be reduced is then quantified as the integrative volume between the simulated discharge $Q_{without\_dam}$ and Q_{with_dam}, but exceeding the desirable discharge $Q_{desirable}$ as seen in Fig. 1. Then, the total flood volume is obtained by using all dams. The intersection of $Q_{without\_dam}$ with the desirable flow $Q_{desirable}$ downstream defines stages I and II denoted by t. In this way, the system is expected to release an amount less than or equal to the total predicted inflow to dams during stage I to leave enough flood control volume. Once stage II is reached, the gates are closed expecting to store water as replenishment. The end of the latter procedure will be defined by time step τ, which could match with the lead-time or till simulated discharge is lower than Q_{opt_gauge}. Therefore, the objective function is defined as to minimize the absolute difference between the flood volume and the total released volume from dams by using the heuristic optimization algorithm SCE developed by Duan et al. (1992).

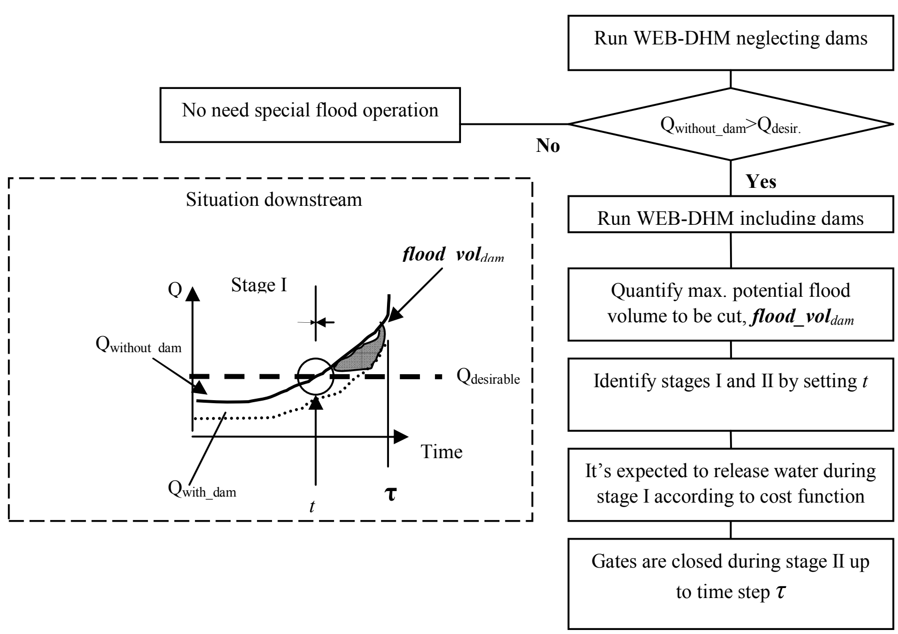
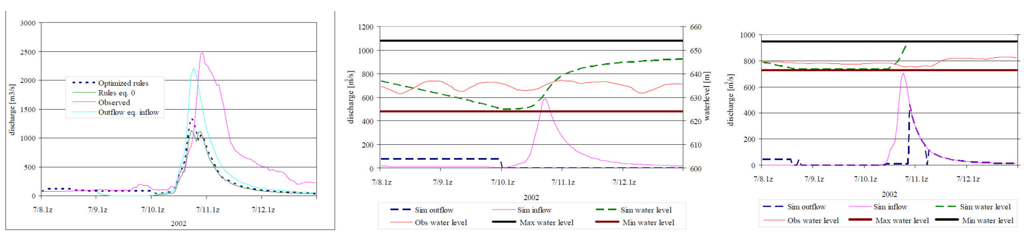


Fig. 1 Objective function for flood control and water use

The meso-scale weather prediction model coupled with the GCM provides meteorological variables namely Grid Point Value (GPV) at 0.125 degree spatial resolution issued every 6 hours and records up to 18 hours lead-time. The GPV data with the coverage of all Japan is originally provided by Japan Meteorological Agency (JMA) and is archived from first of July 2002 up to current days on GEOSS/DIAS at the University of Tokyo. A weight, which is inversely proportional to the standard deviation of the error forecast from the contributing areas to the dams, is introduced into the decision variables which are the dam releases. The error is calculated as the simple bias, absolute bias, Root Mean Square Error (RMSE). In this way, it is expected that lower values of standard deviation (better accuracy of forecast) affect more positively the iteration process of the optimization.

The developed system was applied to an actual dam network in the upper Tone River in Japan. Not only the flood peak and volume was reduced downstream, but also the water volume in the dams was replenished after the flood event. After the iteration process completed by the SCE algorithm, the optimized water release values for Sonohara and Fujiwara dams were obtained. The dam effect at Iwamoto gauge using GPV 7-12 rainfall forecast series can be seen in Fig. 2a. The flood peak and recession curve were reduced due to effective storage of water at the dams. Then, Fujiwara and Sonohara dams' status can be seen in Fig. 2b and 2c. Sonohara dam started operating as free flow from 10 pm on 10 of July 2002 when the maximum safety capacity was reached. On the other hand, simulated water level in Fujiwara dam has reached as high as 646.24 m. These results mean higher potential of hydroelectricity generation.



(a) (b) (c)

Fig. 2 Optimized dam operation using 7-12 series of rainfall prediction at Iwamoto gauge (a), Fujiwara dam (b), and Sonohara dam (b).

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