Estimation of Long-duration Maximum Precipitation Scenarios: A case study of Columbia River Basin

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1. Introduction

The estimation of design floods has been a central issue in hydrology. One of the widely-accepted methodologies to estimate design floods is the Probable Maximum Precipitation (PMP) and Flood (PMF) concept, which has been mainly used for risk assessments of critical infrastructures. However, the conventional approaches to the PMP/PMF estimation cannot handle long-term hydrological and meteorological processes, such as snow accumulation/melt or a series of extreme precipitation events evolving in time and space, due to their temporal and spatial limitations[1]. In snow-covered basins, such as the Columbia River Basin (CRB), what often causes extreme floods are long-term hydrological and meteorological processes that accumulate and melt the falling snow. As such, it is of great importance to develop a methodology to estimate long-duration Maximum Precipitation (MP) so that one can perform a hydrologic analysis to estimate design floods for such basins. Hence, this study aims to develop a new methodology to estimate long-duration MP through a case study for the important drainage areas in the CRB.

2. Study area, model, and data

This study focuses on the drainage areas of two U.S. federal dams in the CRB in Pacific Northwest: Bonneville Dam and Libby Dam[2]. In the CRB, there are more than 250 reservoirs and around 150 hydroelectric projects providing about 70% of the electrical needs in the Pacific Northwest region in the U.S.

This study used the Advanced Research version of Weather Research and Forecasting Model (WRF), version 3.9.1 for the precipitation maximization exercise. The model configuration information including the domain setting, resolution, and physical parameterization schemes is summarized in Hiraga et al. (2021; 2023)[2][3]. This study used the National Centers for Environmental Prediction Climate Forecast System Reanalysis (CFSR) and the National Oceanic and Atmospheric Administration 20th century Reanalysis version 2c (20CRv2c) as initial and boundary conditions of the WRF model.

3. Methodology to estimate Long-duration MP

In the proposed methodology, a long-duration MP scenario is estimated replacing historical storm events by corresponding maximized storm events in a target precipitation sequence, following the similar storm substitution concept in WMO (2009)[1]. First, target storm events for the precipitation maximization are selected based on the Integrated water Vapor Transport (IVT) magnitude and duration[2][3]. Then, basin-average precipitation depths of the selected storm events are maximized using the Atmospheric Boundary Condition Shifting (ABCS) method and Relative Humidity Perturbation method using the IVT threshold (RHP-IVT). The ABCS method can geospatially transpose a target storm by shifting initial and boundary conditions of the model. The RHP-IVT method increases atmospheric moisture at the outer modeling boundary where a target storm passes to intensify the storm. The details on those methods can be found in Hiraga et al. (2021; 2023)[2][3]. Finally, a long duration MP scenario can be estimated replacing historical precipitation by its maximized precipitation in a sequence. In our approach, a long-duration MP can be estimated with accompanying atmospheric and land-surface fields, such as temperature, radiation, and wind speed. Thus, an estimated scenario can be directly used as an input for further hydrologic analysis to estimate extreme floods.

4. Results and discussion

As an example, the precipitation maximization process using

Key words：Probable Maximum Precipitation, Design flood, Atmospheric River, WRF
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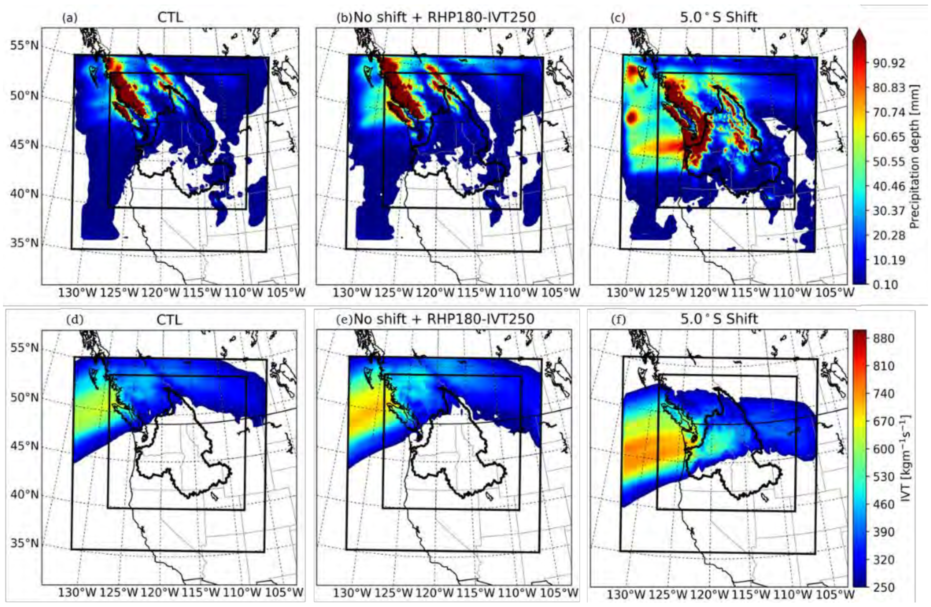

Figure 1 (a-c) Spatial distributions of the accumulated precipitation depths; and (d–f) time-averaged integrated water vapor transport (IVT; $kgm^{-1} s^{-1}$) in the storm event during 1800 UTC January 10–0000 UTC January 13, 1996. (a and d) historical condition (CTL); (b and e) RHP-IVT with unitless multiplier β=1.8 (referred to as RHP180); (c and g) 5.0° south latitudinal shifting. Adapted from Hiraga et al. (2023)[3].

the ABCS and RHP-IVT methods is shown in Figure 1. Figures 1b and 1e show that the RHP-IVT method successfully intensified the IVT magnitude while maintaining the original structure of the storm and led to a corresponding increase in precipitation depths. Figures 1c and 1f show that 5.0° south shifting of the atmospheric boundary condition successfully transposed the target storm from north to south to hit the mid-sector of the CRB. The largely transposed storm event resulted in a substantial increase in precipitation over the CRB. As a result of performing the precipitation maximization exercise for all the selected storm events, a long-duration MP scenario for the target drainage areas can be estimated. Figure 2 shows the estimated MP sequences for the drainage areas of Bonneville and Libby Dams. The estimated MP sequences can be used as an input to hydrologic analysis for a flood risk assessment focusing on long-term hydrometeorological processes.

Acknowledgement: This study was supported by U.S. Army Corps of Engineers (USACE) Grant 3-20B35-Department of Army Engi-W912HZ-17-2-0001.

References

1) World Meteorological Organization (WMO), 2009. Manual on estimation of Probable Maximum Precipitation, WMO-No. 1045.

2) Hiraga, Y et al., 2021. Estimation of Long-duration Maximum Precipitation during a winter season for large basins dominated by Atmospheric Rivers using a Numerical Weather Model. J. Hydrol. 598, 126224. https://doi.org/10.1016/j.jhydrol.2021.126224.

3) Hiraga, Y et al., 2023. Comparison of Numerical Weather Model-based Precipitation Maximization methods: Moisture optimization method, Storm transposition method, and their combination. J. Hydrol. Eng. 28 (1). https://doi.org/10.1016/j.jhydrol.2021.126224.

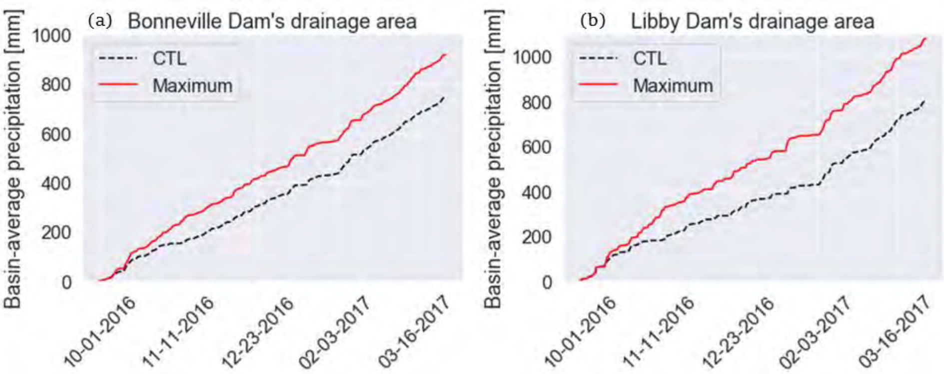

Figure 2 Cumulative basin-average precipitation depths for the drainage areas of Bonneville Dam (a) and Libby Dam (b) during the winter season (Oct-Mar) under historical condition (CTL) and maximized condition (Maximum) Adapted from Hiraga et al. (2021)[2].