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CLIMATE CHANGE IMPACT ON RIVER FLOW OF THE TONE RIVER BASIN, JAPAN

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Future river flow changes in the Tone River basin, Japan, were investigated using a fine resolution distributed hydrologic model and the MRI-AM20km projection output, which is simulated under the A1B climate change scenario. Multiple dam reservoir operations and current water usage information were also considered for realistic river flow simulations. The future water usage and reservoir operation was assumed to be the same as under current conditions. Analysis results show that the river flow change downstream of the basin seems to be insignificant compared to the area upstream of the basin; however, more frequent water shortage days are expected in the future, especially at the Tone-Ozeki station. Revised dam reservoir operation rules should be prepared unless the current water demand changes properly in the future.

Key Words: *Climate change, river discharge, future projection, the Tone River basin*

1. INTRODUCTION

Climate change is expected to strongly affect the hydrologic cycle in the coming decades[1]. In a warmer world, water cycle would be accelerated, shifting seasonal patterns and increasing extreme events in many regions[2,3]. Climate change impacts on the hydrologic cycle should be a main concern if we want a sustainable society in the future. Assessing water resources in the future is difficult due to various uncertain factors related to nature and society[4]. Magnitude of the climate change impact depends on the river basin characteristics, and thus there have been a number of regionalized climate change impact analyses so far[5,6]. Especially in Japan, which has severe seasonal variations of precipitation and high population density, future hydrologic impact analysis should be carried out with much consideration for the complicated geographical shapes of basins and the sophisticated water control and usage information available[7,8].

Under the nationwide climate change research project of Japan, Kakushin21[9], a series of hydrologic impact analyses has been performed using GCM outputs. Takino et al.[10] investigated climate change impacts on river discharge regimes in all Japanese river basins using the output of a super high resolution atmospheric model (hereafter, MRI-AM20km). According to their investigation, annual maximum discharge seems to have increased, especially in the Hokkaido, Northern Touhoku, and Chugoku areas. And the monthly discharge patterns in snow-dominant regions are expected to change, though the change patterns differ region to region. Kim et al.[11] also investigated the precipitation changes across Japan using the MRI-AM20km output, and they showed that we can expect a slight increase in annual precipitation and more apparent increases in summer precipitation at the end of this century. However, because of increased evapo-transpiration amounts, they detected decreased fresh water resources, especially in the Kanto and Tohoku areas. Focusing on the Tone River basin, Takara et al.[12] estimated the water resources changes that will occur in the future with the Standardized Precipitation Index (SPI), and they also found that there will be a greater possibility of drought in the future than the possibility of a flood hazard.

In this study, a very fine resolution distributed hydrologic model was utilized to estimate future river flow changes in the Tone River basin by utilizing the future projection output from the MRI-AM20km. Flow control of seven multi-purpose dams and water usage data about the river basin were also considered to arrive at a realistic simulation of the river flow as it was tested in our previous studies[13,14].

In addition, we analyzed the hydrologic impact on the Tone River basin under the A1B climate change scenario for the near future (2015-2039) and the future (2075-2099), looking at three aspects. First, the flow duration curves were investigated at the following check points in the subject basin: Murakami, Yakatahara, Yattajima, and Tone-Ozeki (see **Fig. 1**). Second, we examined the average discharge and minimum discharge, taking into consideration current water usage, in an attempt to determine any possible water shortage problems in the future. Finally, we compared hourly peak and daily peak discharges from the future projection to that of the current climate scenario to figure out possible changes in flood hazards in the subject basin.

The organization of this paper is outlined below. Section 2 describes the atmospheric input data and the hydrologic model setup. Section 3 provides simulation results of the hydrologic model and analyzes the changes of future river flow, focusing on its seasonal variations. Section 4 describes the changes in the flood peak of the check points in the basin. Finally, the last section summarizes the analysis results.

2. DATA AND METHODOLOGY

(1) Input Data

Very fine resolution of atmospheric output data from the MRI-AM20km, which was developed in the Meteorological Research Institute of Japan, was utilized in this study. The atmospheric model uses the HadISST1 dataset[15] of observed monthly mean climatologic sea surface temperatures (SST) for a boundary condition of the current climate simulation (1979-2003). The SST for the future projection simulation (2015-2039 for the near future and 2075-2099 for the future term) was utilized from the ensemble mean of GCM simulation output under the A1B emission scenario[16]. Refer to Kitho et al.[9], Mizuta et al.[17] and Kitoh and Kusunoki[18] for details on the MRI-AM20km.

Utilizing the MRI-AM20km output in the distributed hydrologic model is the same method employed in our previous studies[13,14]. The output variable, *prcsl* (daily rainfall amounts that reach the soil layer) and *sn2sl* (daily snowmelt amounts in the soil layer) are downscaled into data recording the hourly precipitation output (*precipi*). The *evpsl* (evaporation from the soil layer, daily) and *trnsl* (transpiration from the soil root zone, daily) values were utilized in daily resolution. In this study, there was no bias correction or downscaling on the atmospheric data.

(2) Runoff Simulation

A distributed hydrologic model was built on an object-oriented hydrologic modeling system, OHyMoS[19]. For the hill slope runoff simulation using 250m resolution DEM, we utilized the kinematic wave equation, which incorporates a stage-discharge relationship for sub-surface and surface flow[20]. Channel flow simulation was also conducted by solving the kinematic wave equation and the model produce hourly based hydrograph at each river segment.

The hydrologic model was calibrated manually for the 16 sub-basins in the Tone River basin using the observed input and output data. There are five parameters to be optimized in the model: roughness coefficient n, soil depths ds and dc, and hydraulic conductivities ka and kc. The model parameters have set for each sub-basin was calibrated and validated using the observation data of 1994-1998. Details on the model structure and the calibration procedure are found in Kim et al.[13,14].

The hydrologic model system was previously tested for the evaluation of the MRI-AM20km controlled simulation output. Kim et al.[10] showed that the simulated river discharges match quite well with the historic river discharge, especially for a large basin area (>5,000 km^2) even without any bias correction or downscaling on the atmospheric model output. Considering this characteristic of the MRI-AM20km output, this study focused on an analysis of the Yattajima (5133.6 km^2) and Tone-Ozeki (6058.8 km^2) stations, and the results from the Murakami (1249 km^2) and Yakatahara (1677.5 km^2) stations are given to provide additional information for checking the functionality of dam operation. See **Fig. 1** for the location of the check points.

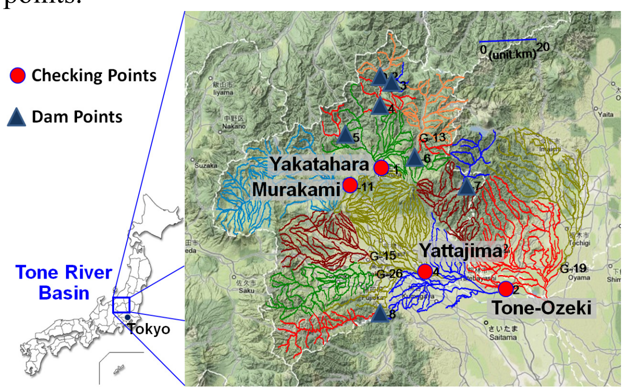

Fig. 1 Basin map of the Tone River basin.

(3) Reservoir Operation and Water Usage

There are seven multipurpose dam reservoirs in the Tone River basin, and the reservoir operation model in this study was designed to reproduce the current release pattern of each dam reservoir. This pattern-reproducing method provides very efficient algorithm for the long-term simulation of a reservoir operation[13,14].

We also included water usage information in the distributed hydrologic model. We surveyed annual water usage data (mainly for living and agricultural usage) of 5 main points in the basin from the Dam Management Office of the Tone River basin, and utilized this information for the model simulation. The water demand at the check points is given as figures in the next section. We may consider future changes in water usage pattern and demanding amount. However, future water demand was assume to be the same as the current one in this study. Based on this condition, it was able to check the impact of climate change on current water usage.

3. SEASONAL PATTERN CHANGES

(1) Analysis with Flow Duration Curves

To understand the seasonal pattern changes at the check points of the basin, flow duration curves (FDC) were produced for present, near future, and future terms. The FDC for each year was prepared first, and representative FDC was generated by averaging the FDC over 25 years. In other words, *n* day river flow of the representative FDC is the average of *n* day river flow of 25 years.

The representative FDCs for check points are given in **Fig. 2**. Because there is no dam reservoir and no flow control upstream of the Murakami station (see **Fig. 2(a)**), the FDCs for that point shows only natural river flow behaviors. There is no significant change in the near future; however, a noticeable increase is there in the low-flow season of the future term. The Murakami station is located in the western upper part of the Tone River basin, and the expected shift in snowmelt discharge in the future will create a different shape of FDC.

The other three points - Yakatahara (**Fig. 2(b)**), Yattajima (**Fig. 2(c)**), and Tone-Ozeki (**Fig. 2(d)**) - are all located downstream of several dam reservoirs, and the simulation results provide two different river flow patterns: without and with dam reservoir controls. When we first checked the natural river flow pattern (no dam reservoir operation), all three points showed similar behaviors with different magnitudes, which are an expected increase of low flow in the future term. The upper region, especially the snowmelt of this region, is highly affected by the increased temperatures at the end of this century. Because of the shifting snowmelt in the upper region (e.g. Yakatahara St.),

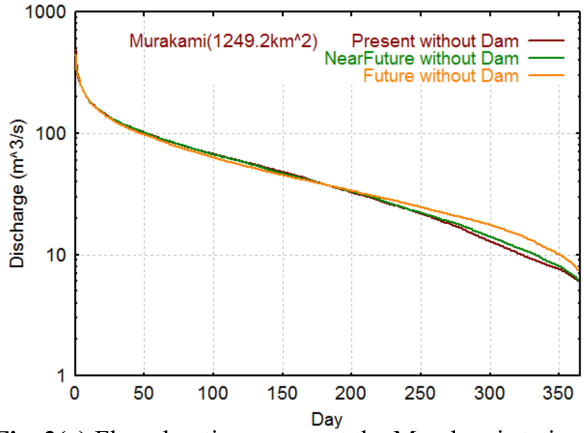

Fig. 2(a) Flow duration curves at the Murakami station.

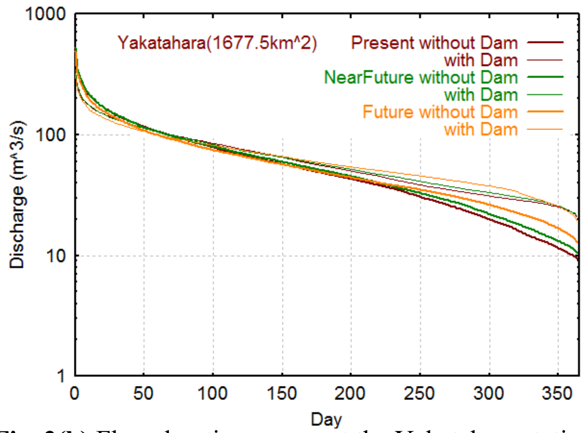

Fig. 2(b) Flow duration curves at the Yakatahara station.

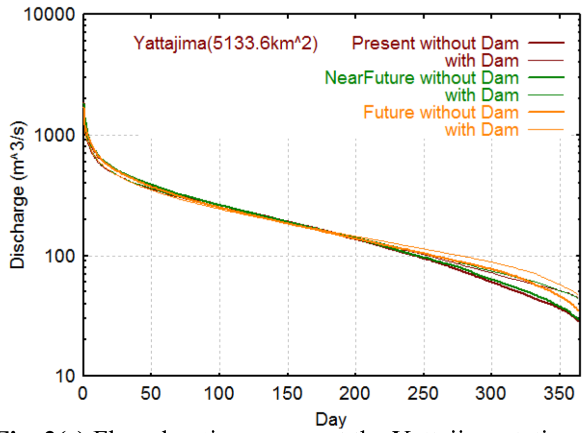

Fig. 2(c) Flow duration curves at the Yattajima station.

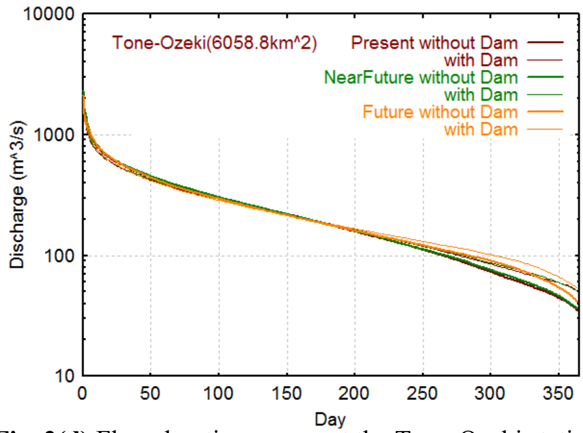

Fig. 2(d) Flow duration curves at the Tone-Ozeki station.

this area will be a subject to experiencing changed river flow regimes in the future.

Currently, there are five dam reservoirs upstream of the Yakatahara station, and one more dam is there at the upper basin of the Tone-Ozeki station. Using the same test utilized in the Yagisawa dam reservoir[9], we tested the reservoir outflow regulations in those six dam reservoirs and simulated a controlled river flow in this study. Focusing on the Yakatahara station, which is located at the right downstream of five dam reservoirs, the reservoir operation effects clearly appeared in the FDCs (see **Fig. 2(b)**). Due to the reservoir operations, the high flow amounts decreased, and it stabilized with increased river flow in the low-flow season. However, the reservoir operation effects decrease as the check point is being away from the reservoirs.

(2) Considering the Water Demand

One of the main reasons to control the river flow with a dam reservoir operation is to provide a safe water supply for those who live downstream. To figure out whether the future river flow will be able to meet the current water demand under the current reservoir operation rules, the minimum river discharge of each day was compared to the amount of water demand.

Fig. 3 shows the average river discharge (to see the seasonal pattern of each term) and the minimum discharge (to check the water supply safety) for the check points. Different from the averaging method used for making the representative flow duration curves (sorting first in maximum order and averaging *n* day's order discharge in each term), the averaged river discharge in **Fig. 3** is a 25-year averaged value of each day from January 1st to December 31th. Using the same method, the minimum discharge is the minimum daily discharge amount of each day within the 25-year period of each term.

At the Murakami station (see **Fig. 3(a)**), where there is no dam reservoir upstream, we noticed a bit of a shift in river flow in the future term during the early spring season. And the minimum discharge of the future term shows a very low flow in the spring season (from approximately day 100 to 130, which corresponds to the middle of April and the middle of May). On the other hand, at the Yakatahara station (see **Fig. 3(b)**), which is located downstream of five dam reservoirs, the minimum discharge during all three terms shows a very similar pattern due to the reservoir operation effects.

The shifted and flattened river flow in the future snowmelt season was also very noticeable at the Yakatahara station before applying the reservoir operation, and the minimum discharge of the future

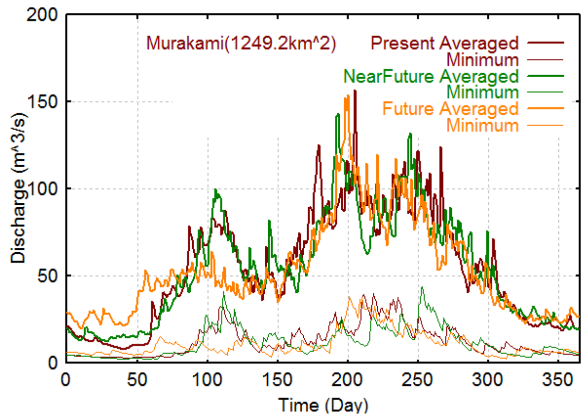

Fig. 3(a) Annual river flow at the Murakami station with the minimum discharge (daily) of each day.

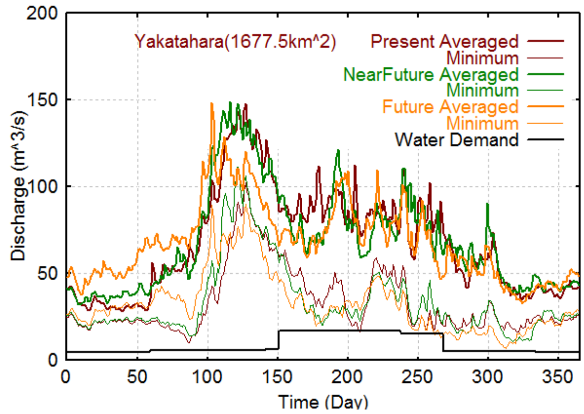

Fig. 3(b) Anl. river flow (daily) at the Yakatahara St.

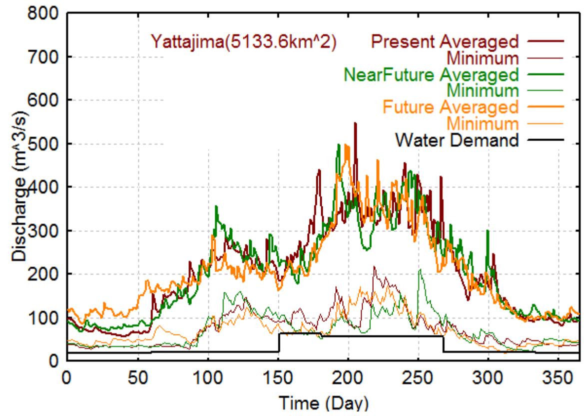

Fig. 3(c) Anl. river flow (daily) at the Yattajima St.

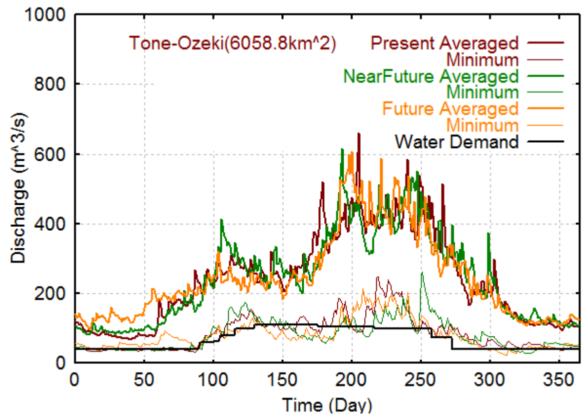

Fig. 3(d) Anl. river flow at the Tone-Ozeki St. Minimum flow (daily) of near future and future term shows more frequent failure of the water supply at this station.

term was not able to satisfy the water demand in many times (it is not shown in the figure). However, river flow regulated by the reservoir operation shows a safe water supply at the Yakatahara station.

While the Yattajima station also is expected to meet the demand for water, the Tone-Ozeki station (see **Fig. 3(d)**) will have a critical failure to meet demands for water supply in both the near future and future, especially in June. The Tone-Ozeki station is the main fresh water source for metropolitan Tokyo. At present, about 75% of all water and 88% of the metropolitan domestic water supply come from the Tone River and its tributaries. On average, 6.5 million m^3/day (around 75 m^3/sec) of water is sent to Tokyo through the Musashi Canal, which starts at the Tone-Ozeki station[21)].

According to the simulation results, continuous water supply through the Musashi Canal can be sustainable in future. However, agricultural water demand in the late spring shows critical failure in the near future and future. It seems the current river flow source in the late spring, which comes from the snowmelt of the upstream, will be shifted to the early spring in the future, and thus it cause limited water resources in some drought years.

The reservoir operation rules adopted in this study follow the current reservoir operation rules not only for the present term but also for the future terms. Thus there is room for improvement to meet the water demand at the Tone-Ozeki station. Revised dam reservoir operation rules should be prepared unless the current water demand changes properly in the future.

4. FLOOD PEAK CHANGES

Finally, hourly peak and daily peak discharges in the near future and future term were compared to the one in the current climate scenario, to figure out any possible changes in flood hazards in the Tone River basin. The hydrologic model produced hourly based hydrograph, and it was up-scaled into daily discharge to get daily peak discharge amount. In each 25-year term, the annual maximum hourly and daily peak discharges were collected and sorted in maximum order. The scatter-gram in **Fig. 4** shows the 25 pairs of the ordered maximum hourly (and daily) peak discharges with the present term as the x-axis and the near-future term as the y-axis.

One is able to see that the future peak discharges are not bigger than those of the present. The peak discharge expected in the future is a similar amount and it is even a smaller amount in some cases (especially at the Murakami St. and Yakatahara St.).

Kim et al.[11)] investigated precipitation changes across Japan using the output of the MRI-AM20km,

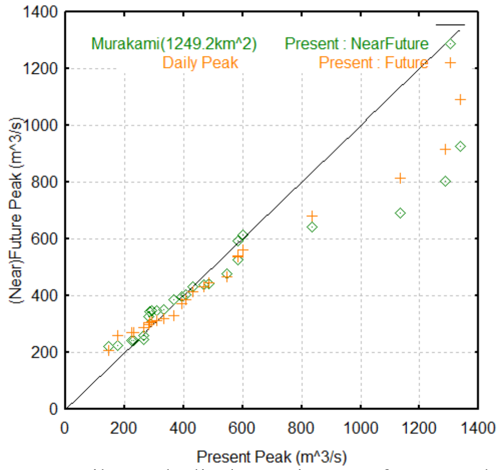

Fig. 4(a) Daily peak discharge in near future and future compared with the present peak discharge at the Murakami St.

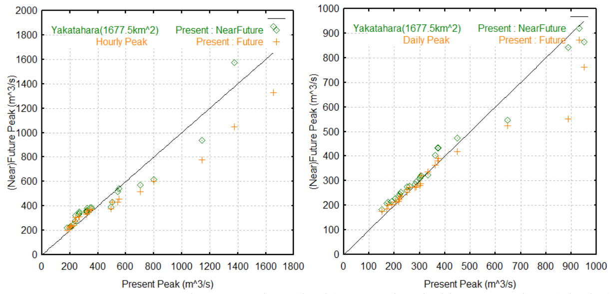

Fig. 4(b) Hourly peak (left) and daily peak (right) discharge at the Yakatahara St.

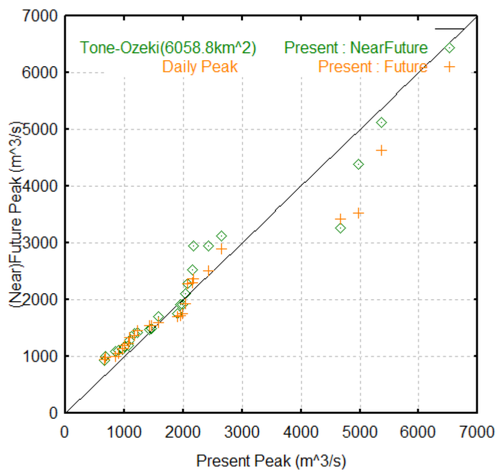

Fig. 4(c) Daily peak discharge at the Tone-Ozek St.

and they showed that maximum precipitation amounts in the future will vary regionally. According to their results, the Chugoku and Shikoku region will apparently experience an increase of daily and hourly maximum rainfall in the near future and the future terms. However, Kanto and some parts of the Tohoku region will have decreased maximums in both the near future and future terms. Analysis of the Tone River basin for this study using the river discharges also showed mildly decreased or slightly changed peak river flows.

It should be noted that the MRI-AM20km is one of general circulation models and the resolution may not yet be precise enough to simulate extreme events on a complicated geographic shape. We should keep in mind that the GCM uses 20km spatially averaged topographic data, which is very rough, to represent complex mountainous areas of Japan, and it adopts several parameterization schemes to generate convective rain-cells. Dynamic downscaled future projection output using a non-hydrostatic regional model might be necessary to analyze such a flood event in small basins of Japan.

5. CONCLUDING REMARKS

This study estimates the hydrologic impacts on the Tone River basin undergoing climate change using a very fine-resolution distributed hydrologic model. The MRI-AM20km projection output for the near future and the future terms was adopted to provide the input data into the hydrologic model. River flow controls provided by multiple dam reservoirs and water usage information were also considered by checking main gauging points in the subject basin.

First, an investigation of the flow duration curves found that a noticeable increase is anticipated in the low flow season in the future. Downstream of the dam reservoirs, the reservoir operation effects clearly appeared in the flow duration curves; high flow amounts decreased and low flow amounts stabilized. However, the reservoir operation effects decrease as the check point is being away from the reservoirs.

Secondly, minimum discharges of each term were examined taking into consideration current water usage information. While the other stations showed that a stable supply will meet the demand for water, the Tone-Ozeki station showed a critical failure of water supply in both the near future and future term, especially in June. Revised reservoir operation rules should be considered unless current water demand changes properly in the future.

Finally, hourly peak and daily peak discharges from the future projection were compared to the one in the current climate scenario. The flood peak discharge of future was not significantly different from the peak in the present climate scenario or showing even decrease amount in some places. Further investigation with other GCM outputs may be necessary to adopt it properly into the extreme event analysis in a complicated topographic region.

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