Investigating potential impact of global warming on historical floods in Asia using large ensemble climate experiments

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1. Background

Extremes of events (i.e.: heavy precipitation and flooding) can have devastating effects on human society and the environment. It is noteworthy that heavy precipitation events have been increased in recent years especially in many parts of the Northern Hemisphere land areas and it is pointed out that the probability of occurred of heavy precipitation increased due to human-induced global warming (increases in greenhouse gases, GHGs) (Min et al. 2010). The latest IPCC-AR5 (Intergovernmental Panel on Climate Change - Fifth Assessment Report) showed the global warming affects the scale and frequency of floods. However, IPCC-AR5 also illustrates that the low confidence regarding the “frequency of past floods changes on a global scale due to anthropogenic global warming” because of limited evidence in the many regions. The reason is that the available instrumental records (especially in the Asia region, there are very few stations that have continuously observed data) and tools to assess river floods changes are limited in spatially and temporally. On the other hand, detecting of past floods changes and determining their causes are important for assessing the repeatability of climate models, improving the accuracy of flood prediction, and important scientific information for measures against global warming. However, with regard to extreme events, such as floods, there have been no studies being conducted the past flood changes in the relatively large area due to the low frequency of occurrence of flood and lack of long-term observations or climate experiments. Fortunately, in recent years, it is become possible to investigate the long-term river floods changes in large areas with increased of river observation networks data and model tool such as a global river and inundation model which can reanalysis long-term river flow by utilizing reanalysis climate data. Furthermore, by using of large ensemble climate experiments, the new technique - Event Attribution (EA) makes possible to quantitatively investigate the contribution of global warming to the extreme phenomenon in the past. Therefore, the main objective of this study is quantifying how much the global warming has affected past Asian floods changes. This study has two sub-objectives in order to get the ultimate goal:

1) Determination of the probability of occurrence for the floods that actually occurred in recent five years (2010-2014), and implemented event attribution to evaluate the impact of past warming on the extreme floods probability of occurrence.

2) Comparing the ease of occurrence of flooding with the probability of long-term occurrence in the Asian region in recent years (2010-2014), and identifying the river basin where global warming already increases the probability of flooding.

2. Data

To investigate the contribution of anthropogenic climate change to Asian floods, data from Emergency Events Database (EM-DAT), Global Runoff Data Centre (GRDC), long-term reanalysis river runoff data derived from CaMa-Flood model (Yamazaki et al., 2011) coupled with a land surface model MATSIRO-GW (Takata et al. 2003) under the forcing by S14 retrospective meteorological forcing dataset (S14FD, Iizumi et al. 2017) and large ensemble of EA experiment data (Shiogama et al. 2013) provided from MIROC5-AGCM (Model for Interdisciplinary Research on Climate version 5 - atmospheric-ocean general circulation model) (Watanabe et al. 2010) were used. Detailed description of ensembles data used in this study are:

1) ALL-LNG (ALL forcing Long period runs): 10-member ensembles for the years 1949-2014 were generated from the AGCM forced by the observed sea surface temperature (SST), sea ice cover (SIC) (HadISST) (Rayner et al., 2003), the historical anthropogenic (GHGs, sulphate and carbon aerosols, tropospheric and stratospheric ozone, and land use change) and natural (solar irradiance changes and large volcanic activity) forcing factors.

2) ALL (ALL forcing runs): same as ALL-LNG, but 100-member ensembles were produced for the 2010-2014 period.

3) NAT_dtr (only natural forcing): 100-member ensembles for 2010-2014 were generated from AGCM forced by historical natural forcing agents and hypothetical “natural” SST and SIC. The natural SST were estimated by removing 1870-2012 linear trends from the HadISST dataset (Christidis and Stott 2014).

4) NAT_CMIP5 (only natural forcing): similar to NAT_dtr, except that anthropogenic SST changes were estimated by taking the differences between SST in the all-forcing historical runs and the natural-forcing historical runs of multiple CMIP5 (Coupled Model Intercomparison Project Phase 5) AOGCMs (coupled -ocean global climate models). The multi-model averaged anthropogenic signals were subtracted from the HadISST data (Stone 2013).

3. Methodology

1) River discharge simulation and selection of flood event

In order to obtain the large ensemble of river discharge, runoff from the EA experiment data (1.4°×1.4° horizontal resolution) were input to CaMa-Flood model and parameterized by sub-grid-scale topography based on 1-km resolution CaMa-Flood
topographic datasets. Final results of simulated daily river discharges (Figure 1, right yellow) from CaMa-Flood model have 0.25°×0.25° resolution.

Four river flood event were identified based on the EM-DAT and news due to there is no enough long-term observation records (i.e.: GRDC). Then, we confirmed whether the flood trend in the selected flood year (the year when the river flood occurred) in EA ALL statistically exceed probability of flood magnitude in long-term EA simulation, derived as 10-year return period in EA-LNG simulation.

2) Estimation of Fraction of attributable Risk (FAR)
The FAR was proposed by Allen (2003), it can be interpreted as an estimate of the probability of necessary causation (by anthropogenic forcing) of an event. The FAR is calculated as:

\[ \text{FAR} = \frac{P_A - P_N}{P_A} \]  

Where \( P_A \) and \( P_N \) is the probability of occurrence of flood event with anthropogenic changes and without anthropogenic changes. When this FAR is positive (negative), it means that global warming has strengthened (suppressed) the occurrence of the flood. If FAR is close to zero, the contribution of global warming to floods is small or can be ignored.

3. Results and discussion

Figure 2 indicates that human-induced climate change increased the probabilities of the Songhua river floods in 2013 and the Yalu river floods in 2010. Furthermore, Table 1 illustrated that the increase in the risk of occurrence of floods in Songhua river floods in 2013 that is attributable to anthropogenic warming by 43 to 62%. In the case of the Yalu river floods, anthropogenic warming increased the risk of floods occurring in 2010 by 39 to 42%. At the same time, even in the same Asian region, anthropogenic warming had almost no effect on the Indus River floods in 2010. In the case of the Brahmaputra river, FAR of two different EA NAT experiments showed the different trends (Table 1 and Figure a&b). Therefore, the impact of global warming on Brahmaputra river floods could not be clarified at the present time.

<table>
<thead>
<tr>
<th>River name</th>
<th>Flood occurrence year</th>
<th>FAR (NAT_dtr)</th>
<th>FAR (CMIP5)</th>
<th>Impact of global warming</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Indus</td>
<td>2010</td>
<td>-0.06</td>
<td>-0.05</td>
<td>Almost no effect</td>
</tr>
<tr>
<td>2. Yalu</td>
<td>2010</td>
<td>0.39</td>
<td>0.42</td>
<td>Enhance</td>
</tr>
<tr>
<td>3. Brahmaputra</td>
<td>2012</td>
<td>-0.36</td>
<td>0.68</td>
<td>Could not be clarify</td>
</tr>
<tr>
<td>4. Songhua</td>
<td>2013</td>
<td>0.62</td>
<td>0.43</td>
<td>Enhance</td>
</tr>
</tbody>
</table>

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Keyword: Anthropogenic warming; Even attribution; Asian floods; MIROC5-AGCM; CaMa-Flood