Flushed away

Addressing the types and hazards of flash floods in the Arctic

Summary

Flash floods pose significant risks to the life and property of Northern communities. In the Arctic, they are often caused by the emerging threat of heavy precipitation as well as glacial retreat and ice-jams in rivers. Efforts should be focussed to improve predictive capabilities and communication of flood risks to the public. Further, protection measures can be taken by local governments and citizens to improve the flood-resilience of these communities.

Explanation of extreme event (MdB)

The event that will be discussed in this paper is flash floods in the Arctic. The NOAA defines flash floods as a flood caused by sudden heavy precipitation or the break of a levee, a dam or an ice jam causing flows ripping through riverbeds or (urban) streets and sweeping everything before them. An already occurring type is because of the ice jams during melting in spring. These **snowmelt floods** (or spring floods) will likely decrease in intensity, as winters are shorter and less cold, the ice build-up is lower and a breakthrough can be reached with a smaller mass (Nillson *et al.* 2015). An example of the other type, sometimes called **summer floods**, happened at the Upper Kuparuk river in July 1999 (Kane *et al.* 2003). In this event, a peak debit was estimated at 3 times larger than the highest annual snowmelt floods. During a 50 h time span 80 mm fell on the catchment (depicted in figure 1), because the thaw layer was only 40 cm deep at the time, hardly any storage could take place. For discharge in the river, a fraction of about 0.73 of the volume is estimated to be from the precipitation event, where normal values are 0.5-0.67.

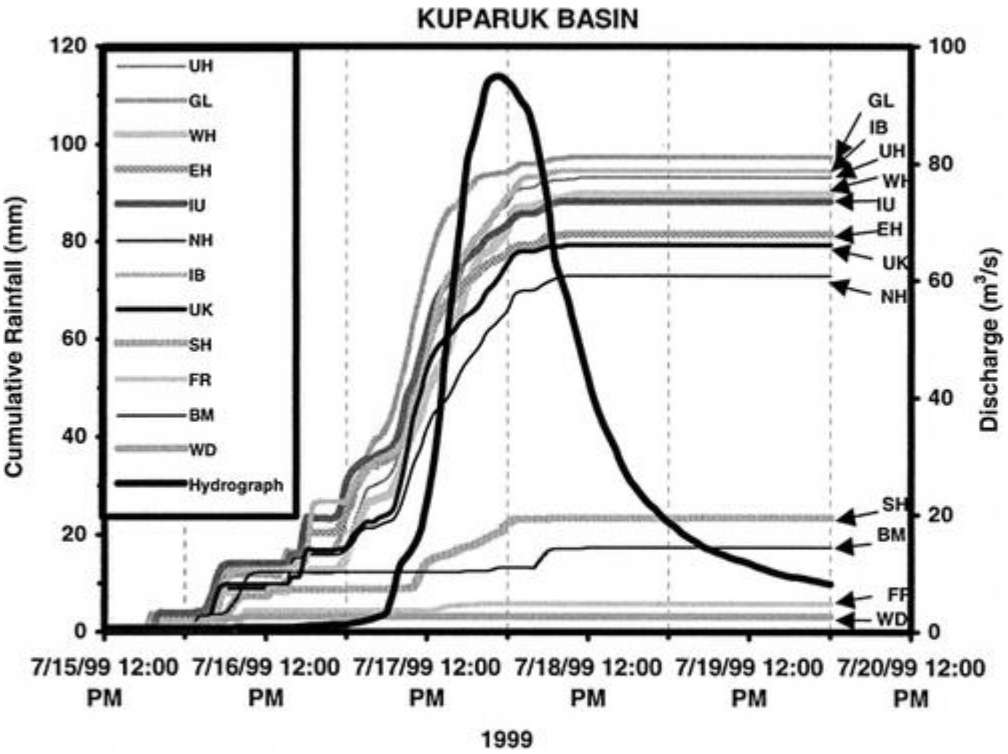

Figure 1: Cumulative rainfall of rain gauges in the Upper Kuparuk River catchment. The dark line represents the hourly mean discharge of the storm. Note that hourly discharge is slightly less than peak instantaneous discharge of 100 m3 s-1.

Figure 2: Effects of a flash flood. Effects are largest on places with little vegetation, such as permafrost or recently burnt areas.

However, with warmer winters more precipitation events occur when extreme precipitation events occur on frozen ground. Another option is heavy rain on snow event. In these cases infiltration is not possible and it will run-off. Moreover, when a small top layer is not frozen it can easily be eroded (Nillson *et al.* 2015). With a 17% increase in heavy rain events in Alaska from 1957 to 2007 (Huber & Gulledge 2011), this trend will likely continue.

To decrease the impact of summer floods we need several types of information and increase our knowledge. The most important data needed is spatial distribution of permafrost in both vertical and horizontal plain, type of precipitation, understanding of how precipitating clouds can change their phase during the event and create rain on-ice event. What we do not have are detailed local observation (Instanes *et al.,* 2016) and knowledge on extreme precipitation processes in the arctic.

Summer floods seem to be less important for the “third pole”, as it is already a large phenomena with monsoon rains. Though summer floods might be better understood when comparing them to monsoon floods.

Stakeholders (MdB)

In the arctic regions, a new type of flash flood is becoming more common, floods caused by heavy precipitation events. Several stakeholders exist for these events, the local inhabitants and infrastructure who might be flushed away as well as other companies. As a result, hydropower dams might need to be able to receive a flash flood year-round. Drinking water companies might see their place of water collection polluted by erosion carried in the floods. However, people looking for things underneath the thaw layers will have an easier time searching, this could be minerals or combustibles.

A possible case to gain more understanding in heavy rain and possible flash floods is July 1999, on the north slope of the upper Kuparuk River (Kane *et al.* 2003).

Added value (I.C Sanchez-Rodriguez)

In general, we consider that an integrated flood warning system is the best strategy to avoid catastrophic flash flood impacts (see Figure 3). Those systems are composed by monitoring sub-systems, forecasting methodologies, and decision-making protocols (Ghavasieh and Norouzi 2009)". The main goal will be to create warnings in advance, that let the communities act instead to react when they face a flash flood.

Firstly, a monitoring system is a network of observational data (in-situ or ex-situ). Not only land meteorological or hydrological observational stations are useful, but also are satellite imagery and aerial vehicles; they can be used to assess the snowpack state in remote places (disciplines such as biodiversity conservation and emergency response in the Arctic already use them (Stapleton *et al.* 2014; Clark *et al.* 2019). Monitoring the basin system is strategic for two main reasons: a) system process understanding and b) creating real-time alerts. The observational information can be used to learn from previous flash flood events (system process understanding). However, it is clear that there is a lack of documentation on flash floods in the Arctic (Kane *et al.* 2003). Our advice is convoking the academics to create interdisciplinary research teams that can use monitoring data and social research to understand how flash floods have impacted the communities in the past.

Secondly, a flood potential relies on the water available upstream of rivers, in the form of ice and snowpack, and also relies upon late and mid-winter rainfall amount (Trenberth 2011). A successful forecast should be able to predict in advance the season and rate of snowmelt in the basin and also the precipitation rate during the snowmelt season. A good energy balance forecast is strategic to anticipate the snowmelt rate (Kane *et al.* 1997). While for rainfall forecasts, can be used the traditional methodologies; that includes the amount of moisture, cyclogenesis, topography, and others (Kane *et al.* 2003). Studies suggest that forecasts methodologies for energy balance and rainfall should always be under review. For instance, there is a strong relationship between rainfall rate changes and the snowmelt. According to Bintanja (2018) in the Arctic regions, the rainfall lowers the albedo. Given that the rainfall in arctic regions relies upon local and remote warming, plus the polar amplification (significant projected temperature changes) (Shoji *et al.* 2015), the challenge is to adapt the forecasting methodologies for those new changes in the rainfall cyclogenesis and the consequent changes over the energy balance.

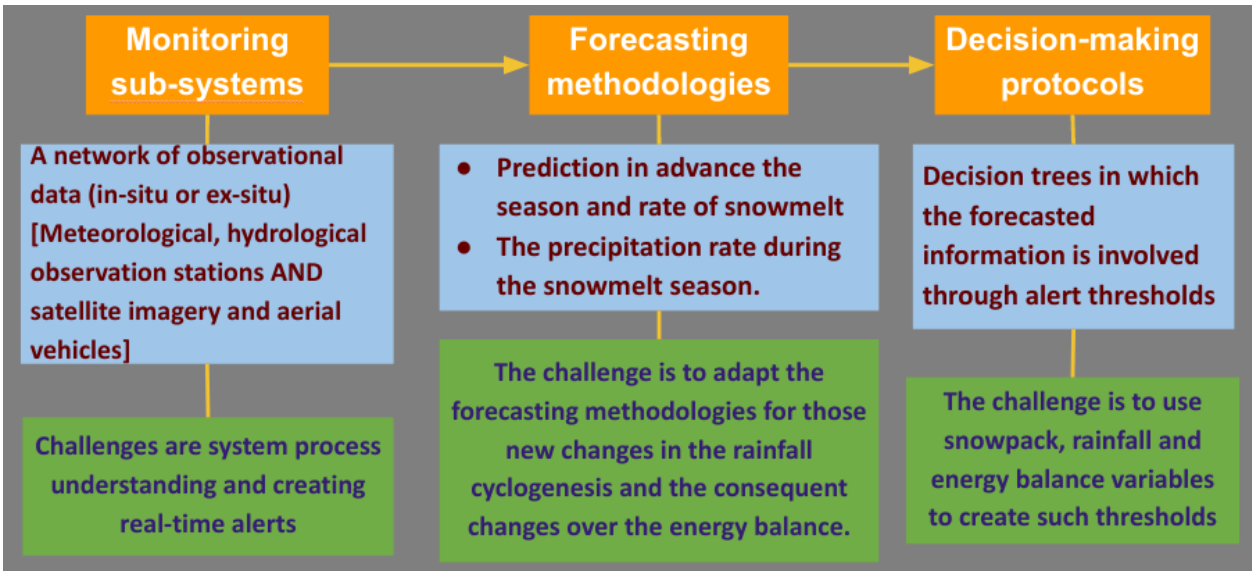

Figure 3: Highlights for an integrated flood warning system

Finally, decision-making protocols include complex decision trees in which the forecasted information is involved. A common way to use the forecasted meteorological and hydrological information is through alert thresholds. Once the forecast system creates predict the value of the variables, those are used to detect a flood probability. Most common practices use intensity-duration-frequency curves (Ghavasieh and Norouzi 2009); however, in the Arctic context, the challenge is to use snowpack, rainfall and energy balance variables to create such thresholds.

Recommendations (Joseph)

Improvements in prediction are especially important to facilitate responses of Northern communities whose remote nature adds to the logistical challenges of preparing for flash floods. As in other regions, improving both models and observations related to heavy rainfall will contribute to this effort (American Meteorological Society Council, 2000). Further, and specific to the Arctic, better flash flood forecasting could be developed from enhanced modelling and observational capabilities with regards to retreating glaciers (Instanes *et al,* 2016). An example of the progress from such research can be seen with regards to the Greenland ice sheet. By applying a surface mass balance model, van As *et al* (2017) used local observations to force the equations solving for the surface mass and surface energy of the ice sheet and thus predict resulting discharge into the Watson River. This model successfully calculated ice-sheet runoff to within 1.5m of ice observations.

Figure 4: The washout of the Watson River Bridge in Kangerlussuaq, Greenland following a record-setting proglacial discharge (Mikkelsen *et al.* 2016).

While a greater predictive capability is foundational to improved flash flood responses in Northern communities, other general and regionally-specific mitigations should be considered. Generally, the focus should be on appropriate communication to both local leadership as well as the general public in effective communities. Effective risk communication with regards to flash floods has been found to increase general community awareness of both preventative and reactive measures which can improve overall public safety (Bodoque *et al.* 2019). In consideration of the prolific nature of ice-jam floods in the Northern communications, the benefits of proactive ice-jam demolition - as is practiced in Edeytsy, Russia - should be considered (Kontar *et al.* 2018). Additionally, van As *et al.* (2017) noted that in some cases, such as that of the Watson River in Greenland, early warning systems deployed upstream could allow civil authorities and the public to prepare for transiting flood waters.

Considerations (MdB)

As heavy precipitation events often find their origin in the mid to low latitudes it is good to keep the weather system as a whole into account.

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