Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-117-AC1, 2016
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Hydrology and Earth System Sciences Discussions

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Interactive comment

Interactive comment on "Peak river flows in cold regions – Drivers and modelling using GRACE satellite observations and temperature data" *by* S. Wang et al.

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Received and published: 7 June 2016

We greatly appreciate the comments which helped improve the paper. The main objectives of this paper are (1) to test the model performance of Wang and Russell (2016) in forecasting the magnitudes of peak flows for the Mackenzie River and (2) to identify the differences in major drivers for determining the peak flows between the Mackenzie River and Red River. The date for peak river flow in the study is from in situ observations, and it is used to estimate the overall water travel time by comparing it with the modelled date for peak snowmelt.

We added a brief summary for the studies by Frappart et al. (2006, 2011) for estimating SWE from the GRACE TWS in the Introduction section, and replaced "footprint" by

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“resolution” throughout the manuscript.

Section 2 is separated into three subsections: 2.1 Study Basin, 2.2 Datasets, and 2.3 Basin Hydroclimatology, to make the content better presented. More details about the GRACE data, including spatial resolution and the definition and application of scaling factors, are added. The leakage error in TWS, which is estimated at less than 10 mm of water, or less than 9% of the average seasonal variation of TWS, is relatively small. The impact of leakage error on the peak river flow estimates is evaluated and discussed on Page 20 (revised version). Overall, the impact was found to be small (MAE mostly under 0.06 mm day-1, or 4% of the mean peak flow value). The scaling factors were based on NCAR’s land surface model CLM4. It includes simulation for surface water, soil water and snow, but not groundwater storage in aquifers. The lack of groundwater components and the uncertainties in CLM outputs affect the effectiveness of the scaling process. Fortunately, the hydrology of the basin during the study season (winter-early spring) is primarily determined by the snow processes, while groundwater variation is relatively small.

The missing reference for the method is added. The baseflow model we used is a modified Linear Reservoir model which is widely used in baseflow recession analysis. It is difficult to construct physically-based baseflow models for the basin due to very limited data and knowledge for the basin hydrogeology. Also, since baseflow contribution to the flood is very small in our case, the impact of its estimation uncertainty from our model on flood forecasting is minor. Our model doesn’t explicitly include the physical details of a basin. High spatial heterogeneities within a basin (e.g., difference in breakup time for a large basin) would likely increase uncertainties in estimates. We investigated the scale impact on model performance by comparing the results for the Mackenzie River basin (large) and the Red River basin (small). As expected, the model performs better for the smaller basin which is more homogeneous in climate (including breakup time), land surface, and hydrogeological conditions. More discussions on this have been added in the paper. We selected Red River basin instead of a sub-basin

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within Mackenzie River basin as (1) Red River basin has large differences in hydroclimate with that in Mackenzie River basin. By comparing results from them we can better reveal the differences in major drivers for the peak river flows over different regions, which is a major objective of this study; and (2) Red River basin is more homogeneous with better observations. However, it is worth noting that even for the small basin of Red River (whose size is at the lower limit for GRACE resolution), the size is still large enough to have significant spatial differences in snow breakup dates (see discussion in Wang and Russell, 2016). Moreover, small basins tend to have large uncertainties in the TWS estimates due to the coarse resolution of GRACE satellites. This can be clearly seen by the large difference of impacts of the leakage and measurement errors in the TWS on the flood estimates as discussed in the paper. The paper has been revised by adding clarifications and more discussion on this.

The break-up and peak snowmelt dates are obtained in the snowmelt model which has a daily time step. The GRACE data is only used to estimate the initial condition (TWE) for the snowmelt model. As the snow pack accumulation is a rather smooth process, the impact of monthly temporal resolution of GRACE data on the model estimates is largely reduced. However, it is agreed that GRACE TWS derived on a daily basis would better fit the modelling scheme and improve the model estimates. In particular, we believe that GRACE TWS daily data will have large potentials for many other applications such as estimating storm-induced flood, soil moisture, and snowmelt process. We compared the results from the same model over different basins as one main objective of the study is to identify the differences in major drivers for determining the peak flows between different basins, with an intention to provide a simple approach to complement the existing operational flood forecasting approaches by using additional data from GRACE. The flood in our case is mainly a result of snowmelt. To our understanding, WGHM uses degree-day for snow simulation and it assumes that snow melts with a constant rate when temperature is above 0°C (2 mm/day per degree in forests and 4 mm/day in other land cover types). Our snowmelt model uses similar algorithm to that in WGHM, but its parameters (e.g., melt rate) are estimated based on observation

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data in the basin. As such, we expect our results better reflect the snowmelt process in the basins. For more detailed hydrological studies, we have developed the land surface model EALCO which has comprehensive algorithms for snow simulation such as dynamic snow layering and fractional cover algorithms, dynamic snow albedo, snow cover compaction, destructive metamorphisms, and the implicit solutions of heat and melt water transfer equations in the snow pack (Zhang et al., 2008). However, comprehensive hydrological or land surface models demand a large number of data inputs and are more difficult to be used for operational flood forecasting. Compared with dry land or some other lands such as forests, basins with wetland and water bodies have higher water dischargeability, as shown in our results. This is accounted in our approach by the parameter (a) fitting using observed Q. Surface runoff is minimal in winter as there is basically no liquid precipitation during the season. The river flow in winter is mainly associated with groundwater and water body discharges. The model forecasting capability relies on the snowmelt model using temperature input, while GRACE provides the initial condition (SWE) at the breakup, so it is not necessary to have GRACE data that is months in advance. However, it is worth mentioning that GRACE data in the epoch that is a couple of months before the spring breakup might still be very useful for freshet flood warning, as snow packs have high correlations between the two epochs in our study region (e.g., February vs. April). The GRACE TWS error is estimated at 9.9 mm, which is about 8.5 % of the average seasonal variation of TWS (see Section 2.3). It is estimated following the approach of Wahr et al. (2006) (see Section 2.2). The paper has been revised by adding more discussion on this. The reference of Kurtenbach et al. (2012) is added.

Tables 1, 2, and 3 in the previous version are merged as suggested.

Figure 1 is revised by adding the map for Canada and locating Mackenzie River basin in the map (attached below), as suggested.

References: Wang, S. and Russell, H. 2016. Forecasting snowmelt-induced flooding using GRACE satellite data: A case study for the Red River watershed. Canadian

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Zhang, Y., Wang, S., Barr, A.G., and Black, T.A. 2008. Impact of snow cover on soil temperature and its simulation in the EALCO model. Cold Regions Science and Technology, 52, 355-370.

Revised Figure 1.

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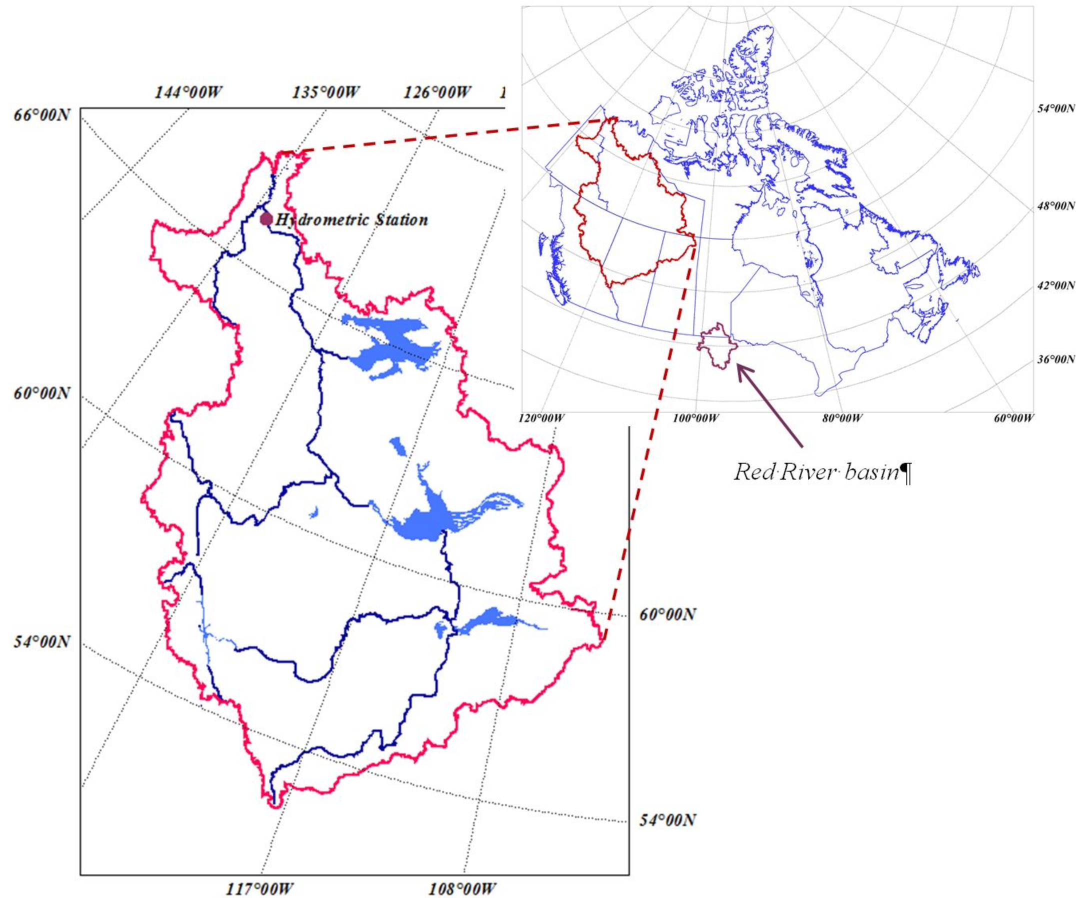

Fig. 1. Map for the Mackenzie River basin and the hydrometric station used in this study. The Red River basin is shown in the map for Canada.

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